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# (54) METHOD AND APPARATUS FOR THE PRODUCTION OF PLASTIC LENSES

VERFAHREN ZUR HERSTELLUNG VON LINSEN AUS KUNSTSTOFF

PROCEDE ET APPAREIL DE PRODUCTION DE LENTILLES EN PLASTIQUE

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## Description

The present invention relates generally to methods, apparatus and compositions for making plastic lenses.

It is conventional in the art to produce optical lenses by thermal curing techniques from the polymer of diethylene glycol bis(allyl)-carbonate (DEG-BAC).

The polymer of DEG-BAC exhibits desirable optical and mechanical properties. These properties include high light transmission, high clarity, and high index of refraction together with high abrasion and impact resistance. These properties in the past made DEG-BAC one of the leading monomers in the manufacture of high quality lenses, face shields, sun and safety glasses. Other properties of DEG-BAC, however, such as its slow rate of polymerization, make it an undesirable monomer in the manufacture of these items.

In addition, the thermal curing techniques for polymerizing DEG-BAC to produce optical lenses have several disadvantages and drawbacks. One of the most significant drawbacks is that it may take approximately 12 hours to produce a lens according to thermal curing techniques. A lens forming mold, therefore, can produce at most two lenses per day.

Moreover, thermal curing techniques employ a thermal catalyst so that a polymerizable mixture of DEG-BAC and catalyst will slowly polymerize even while refrigerated. The polymerizable mixture therefore has a very short shelf life and must be used within a short time or it will harden in its container.

Furthermore, the thermal catalysts utilized according to the thermal techniques are quite volatile and dangerous to work with, thus requiring extreme care in handling.

Curing of a lens by ultraviolet light presents certain problems that must be overcome to produce a viable lens. Such problems include yellowing of the lens, cracking of the lens or mold, optical distortions in the lens, and premature release of the lens from the mold.

US-A-4919850 relates to a method and apparatus for making lenses. A monomer is used with initiators in conjunction with a molding apparatus to mold plastic lenses of optical quality. The molding material includes a composition of liquid monomer with a thermal initiator and UV initiator each of which can be activated during the molding process. Initially the molding forms with the liquid monomer compositions therein are heated to activate the thermal initiator and form the molding material into a gel. The gelled material is then subjected to a UV light source for completing the cure. During the curing step a cooling medium, such as a liquid bath or air is used to achieve a desired cooling effect.

Unfavourable results may be achieved if a cooling fluid is passed over the lens forming material in one direction only, since the side opposite the source of fluid tends to remain hotter because the fluid passing over it has picked up heat from the first side.

The present invention provides methods and apparatus for making plastic lenses, such as optical lenses for use in eyeglasses and the like.

According to one aspect of this invention there is provided a method for making a plastic lens, comprising the steps of placing a polymerizable lens forming material in a mold cavity defined between a first mold member with a face, and a second mold member with a face, and a gasket; and directing ultraviolet rays towards at least one of the first or second mold members or said gasket while substantially simultaneously cooling the first mold member and the second mold member, the cooling being effected by directing air at a temperature of between 0°C and less than 20°C towards the faces of the first and second members, the air being directed from the edges of the first mold member to the center of the first mold member, and from the edges of the second mold member to the center of the second mold member. In this manner the air that contacts the edges of the mold members is approximately the same temperature at all the edges of the mold members, and approximately the same at all radii from the center of the mold members (with some variances due to variances in the cavity thickness at certain radii). Thus substantially the same thickness of the lens material are subjected to air that is substantially the same temperature, resulting in a more even cooling of the lens material.

In a preferred method in accordance with the invention, for making a plastic lens with a desired curvature, the mold cavity defines a theoretical curvature that is different from the desired curvature. The ultraviolet rays are directed towards at least one of the first and second mold members such that portions of the material in the cavity receive different intensities of ultraviolet light from other portions of the material in the cavity, thereby allowing the material to form a lens with the desired curvature. In such a method, following demolding of the lens, the lens may be heated and during the heating step the lens adopts the desired curvature.

The invention also provides an apparatus for making a plastic lens comprising a first mold member, a second mold member spaced apart from the first mold member, the first and second mold members each having a face defining a mold cavity; an ultraviolet light generator for generating and directing ultraviolet light towards at least one of the first and second mold members during use; an ultraviolet light filter disposed between the ultraviolet light generator and the first mold member, and between the ultraviolet light generator and the second mold member, the apparatus further comprising a distributor adapted to direct air at a temperature of between 0°C and less than 20°C towards the first and second mold members while the ultraviolet light is substantially simultaneously directed towards at least one of the first and second mold members during use, the distributor being connected to distribute air during use from the edges of the first mold member to the center of the first mold member, and from the edges of the second mold member to the center of

the second mold member.

Further objects, features and advantages of the methods and apparatus of the present invention will be more fully appreciated by reference to the following detailed description of presently preferred but nonetheless illustrative embodiments in accordance with the present invention when taken in conjunction with the accompanying drawings in which:

Fig. 1 is a perspective view of an apparatus for producing a plastic lens according to the present invention;

Fig. 2 is a cross-sectional view of the apparatus of the present invention taken along line 2-2 of Fig. 1;

Fig. 3 is a cross-sectional view of the apparatus of the present invention taken along line 3-3 of Fig. 2;

Fig. 4 is a detail view of a component of the apparatus of the present invention;

Fig. 5 is a detail view of a component of the apparatus of the present invention;

Fig. 6 is a cross-sectional view of a lens cell for use in the apparatus of the present invention; and

Fig. 7 is a schematic block diagram of an alternate process and system for making and postcuring a plastic lens.

While various aspects of the present invention are hereinafter illustrated and described as being particularly adapted for the production of a plastic lens for use in eyeglasses, it is to be understood that lenses for other uses can also be produced, such as safety glasses as well as lenses having high quality optical use for instrument sightings, photography and light filtration.

Therefore, the present invention is not to be limited only to the embodiments illustrated in the drawings, because the drawings are merely illustrative of the wide variety of specific embodiments of the present invention.

Referring now to Fig. 1, a plastic lens curing chamber of the present invention is generally indicated by the reference numeral 10. The lens curing chamber 10 communicates through a plurality of pipes 12 with an air source (not shown), the purpose of which will be discussed below.

As shown in Fig. 2, the plastic lens curing chamber 10 may include an upper lamp chamber 14, an irradiation chamber 16, and a lower lamp chamber 18. The upper lamp chamber 14 may be separated from the irradiation chamber 16 by a plate 20. The lower lamp chamber may be separated from the irradiation chamber 16 by a plate 22. The upper lamp chamber 14, the irradiation chamber 16, and the lower lamp chamber 18 may be isolated from ambient air by means of upper lamp chamber doors 24, irradiation chamber doors 26, and lower lamp chamber doors 28, respectively. While the upper lamp chamber doors 24, the irradiation chamber doors 26 and the lower lamp chamber doors 28 are shown in Fig. 1 as including two corresponding door members, those of ordinary skill in the art will recognize that the doors 24, 26 and 28 may comprise a single door member. The upper lamp chamber doors 24, the irradiation chamber doors 26 and the lower lamp chamber doors 28 may be slidingly mounted in guides 30. As shown in Fig. 2, vents 32 may communicate with upper lamp chamber 14 and lower lamp chamber 18 by way of corresponding vent chambers 34 and openings 36 disposed in plate 20 and plate 22. Each vent 32 may be shielded by a vent cover 38.

As shown in Fig. 3, vents 33 may be disposed in the irradiation chamber doors 26 and communicate with irradiation chamber 16. Each vent 33 may be shielded by a vent cover 35.

As shown in Figs. 2 and 3, a plurality of light generating devices or lamps 40 may be disposed within each of upper lamp chamber 14 and lower lamp chamber 18. Preferably, upper lamp chamber 14 and lower lamp chamber 18 each include three lamps 40 that are arranged in a triangular fashion in which the lamps 40 in the upper lamp chamber 14 are disposed with the point of the triangle pointing upwards whereas the lamps 40 in the lower lamp chamber 18 are disposed with the point of the triangle pointing downward. The lamps 40, preferably, generate ultraviolet light having a wavelength in the range of approximately 300 nm to 400 nm since the effective wavelength spectrum for curing the lens forming material lies in the 300 nm to 400 nm region. The lamps 40 may be supported by and electrically connected to suitable fixtures 42.

An exhaust fan 44 may communicate with upper lamp chamber 14 while an exhaust fan 46 may communicate with lower lamp chamber 18.

As noted above, the upper lamp chamber 14 may be separated from the irradiation chamber 16 by plate 20. Similarly, lower lamp chamber 18 may be separated from the irradiation chamber 16 by plate 22. The plates 20 and 22 may include apertures 48 and 50, respectively through which the light generated by lamps 40 may be directed so as to impinge upon a lens cell 52 (shown in phantom in Fig. 2). The diameter of the lens cell 52 preferably, is approximately 74 mm. The apertures 48 and 50 preferably range from about 70 mm to about 140 mm. An upper light filter 54 rests upon plate 20 while a lower light filter 56 rests upon plate 22 or is supported by brackets 57. The upper light filter 54 and lower light filter 56 are shown in Fig. 2 as being comprised of a single filter member, however, those of ordinary skill in the art will recognize that each of the upper light filter 54 and lower light filter 56 may be comprised of two filter mem-

bers. The components of upper light filter 54 and lower light filter 56 preferably are modified depending upon the characteristics of the lens to be molded. For instance, in a preferred embodiment for making negative lenses, the upper light filter 54 includes a plate of Pyrex glass that is frosted on both sides resting upon a plate of clear Pyrex glass. The lower light filter 56 includes a plate of Pyrex glass frosted on one side resting upon a plate of clear Pyrex glass with a device for reducing the intensity of ultraviolet light incident upon the center portion in relation to the edge portion of the lens being disposed between the plate of frosted Pyrex and the plate of clear Pyrex glass.

Conversely, in a preferred arrangement for producing positive lenses, the upper light filter 54 includes a plate of Pyrex glass frosted on one or both sides and a plate of clear Pyrex glass resting upon the plate of frosted Pyrex glass with a device for reducing the intensity of ultraviolet light incident upon the edge portion in relation to the center portion of the lens being disposed between the plate of clear Pyrex glass and the plate of frosted Pyrex glass. The lower light filter 56 includes a plate of clear Pyrex glass frosted on one side resting upon a plate of clear Pyrex glass with a device for reducing the intensity of ultraviolet light incident upon the edge portion in relation to the center portion of the lens being disposed between the plates of clear Pyrex glass. In this arrangement, in place of a device for reducing the relative intensity of ultraviolet light incident upon the edge portion of the lens, the diameter of the aperture 50 can be reduced to achieve the same result, i.e. to reduce the relative intensity of ultraviolet light incident upon the edge portion of the lens.

It will be apparent to those skilled in the art that each filter 54 or 56 could comprise a plurality of filter members or comprise any other means or device effective to reduce the light to its desired intensity, to diffuse the light and/or to create a light intensity gradient across the lens cell 52.

Preferably, the upper light filter 54 or the lower light filter 56 each comprise at least one plate of Pyrex glass having at least one frosted surface. Also, either or both of the upper light filter 54 and the lower light filter 56 may include more than one plate of Pyrex glass each frosted on one or both surfaces, and/or one or more sheets of tracing paper. After passing through frosted Pyrex glass, the ultraviolet light is believed to have no sharp intensity discontinuities which is believed to lead to a reduction in optical distortions in the finished lens. Those of ordinary skill in the art will recognize that other means may be used to diffuse the ultraviolet light so that it has no sharp intensity discontinuities.

Disposed within the irradiation chamber 16 are a left stage 58, a center stage 60, and a right stage 62, each of which includes a plurality of steps 64. The left stage 58 and center stage 60 define a left irradiation chamber 66 while the right stage 62 and center stage 60 define a right irradiation chamber 68. A cell holder 70, shown in phantom in Fig. 2 and in detail in Fig. 4, may be disposed within each of left irradiation chamber 66 and right irradiation chamber 68. The cell holder 70 includes a peripheral step 72 that is designed to allow a cell holder 70 to be supported upon complementary steps 64 of left stage 58 and center stage 60, and center stage 60 and right stage 62, respectively. As shown in Fig. 4, each cell holder 70 also includes a central bore 74 to allow the passage therethrough of ultraviolet light from the lamps 40 and an annular step 76 which is designed to support a lens cell 52 in a manner described below.

As shown in Fig. 6, each lens cell 52 includes opposed mold members 78, separated by an annular gasket 80 to define a lens molding cavity 82. The opposed mold members 78 and the annular gasket 80 may be selected in a manner to produce a lens having a desired diopter.

The mold members 78, preferably, are formed of any suitable material that will permit rays of ultraviolet light to pass therethrough. The mold members 78, preferably, are formed of glass. Each mold member 78 has an outer peripheral surface 84 and a pair of opposed surfaces 86 and 88 with the surfaces 86 and 88 being precision ground. Preferably the mold members 78 have desirable ultraviolet light transmission characteristics and both the casting surface 86 and non-casting surface 88 preferably have no surface aberrations, waves, scratches or other defects as these may be reproduced in the finished lens.

As noted above, the mold members 78 are adapted to be held in spaced apart relation to define a lens molding cavity 82 between the facing surfaces 86 thereof. The mold members 78 are held in a spaced apart relation by a T-shaped flexible annular gasket 80 that seals the lens molding cavity 82 from the exterior of the mold members 78. In use, the gasket 80 is supported on the annular step 76 of the cell holder 70.

In this manner, in the embodiment of the present invention that is illustrated in Fig. 6 the upper or back mold member 90 has a convex inner surface 86 while the lower or front mold member 92 has a concave inner surface 86 so that the resulting lens molding cavity 82 is shaped to form a lens with a desired configuration. Thus, by selecting the mold members 78 with a desired surface 86, lenses with different characteristics, such as focal lengths, may be made by the apparatus 10. Such techniques are well known to those skilled in the art, and will therefore not be further discussed.

Rays of ultraviolet light emanating from lamps 40 pass through the mold members 78 and act on a lens forming material disposed in the mold cavity 82 in a manner discussed below so as to form a lens. As noted above, the rays of ultraviolet light pass through a suitable filter 54 or 56 to impinge upon the lens cell 52.

The mold members 78, preferably, are formed from a material that will not allow ultraviolet radiation having a wavelength below approximately 300 nm to pass therethrough. Suitable materials are Schott Crown, S-1 or S-3 glass manufactured and sold by Schott Optical Glass Inc., of Duryea, Pennsylvania or Corning 8092 glass sold by Corning Glass of Corning, New York.

The annular gasket 80 may be formed of vinyl material that exhibits good lip finish and maintains sufficient flexibility

at conditions throughout the lens curing process. In a preferred embodiment, the annular gasket 80 is formed of silicone rubber material such as GE SE6035 which is commercially available from General Electric. In another preferred embodiment, the annular gasket 80 is formed of copolymers of ethylene and vinyl acetate which are commercially available from E. I. DuPont de Nemours & Co. under the trade name ELVAX®. Preferred ELVAX® resins are ELVAX® 350 having a melt index of 17.3-20.9 dg/min and a vinyl acetate content of 24.3-25.7 wt. %, ELVAX® 250 having a melt index of 22.0-28.0 dg/min and a vinyl acetate content of 27.2-28.8 wt. %, ELVAX® 240 having a melt index of 38.0-48.0 dg/min and a vinyl acetate content of 27.2-28.8 wt. %, and ELVAX® 150 having a melt index of 38.0-48.0 dg/min and a vinyl acetate content of 32.0-34.0 wt. %. Regardless of the particular material, the gaskets 80 may be prepared by conventional injection molding or compression molding techniques which are well-known by those of ordinary skill in the art.

As shown in phantom in Fig. 2, in section in Fig. 3, and in detail in Fig. 5, an upper and lower air distribution device 94 is disposed in each of left irradiation chamber 66 and right irradiation chamber 68. Each air distribution device 94 is connected to a pipe 12. As shown in Fig. 5, each air distribution device 94 includes a plenum portion 95 and a cylindrical opening 96 having orifices 98 disposed therein to allow for the expulsion of air from the air distribution device 94. The diameter of the orifices 98 varies around the circumference of cylindrical opening 96 preferably reaching a maximum when directly opposite the plenum portion 95 of air distribution device 94 and preferably reaching a minimum immediately adjacent the plenum portion 95. In addition, the orifices 98 are designed to blow air toward a lens cell 52 that may be disposed in a lens cell holder 70 and installed in left irradiation chamber 66 or right irradiation chamber 68.

In operation, the apparatus of the present invention may be appropriately configured for the production of positive lenses which are relatively thick at the center or negative lenses which are relatively thick at the edge. To reduce the likelihood of premature release, the relatively thick portions of a lens preferably are polymerized at a faster rate than the relatively thin portions of a lens.

The rate of polymerization taking place at various portions of a lens may be controlled by varying the relative intensity of ultraviolet light incident upon particular portions of a lens. The rate of polymerization taking place at various portions of a lens may also be controlled by directing air across the mold members 78 to cool the lens cell 52.

For positive lenses the intensity of incident ultraviolet light, preferably, is reduced at the edge portion of the lens so that the thicker center portion of the lens polymerizes faster than the thinner edge portion of the lens. Conversely, for a negative lens, the intensity of incident ultraviolet light, preferably, is reduced at the center portion of the lens so that the thicker edge portion of the lens polymerizes faster than the thinner center portion of the lens. For either a positive lens or a negative lens, air may be directed across the faces of the mold members 78 to cool the lens cell 52. As the overall intensity of incident ultraviolet light is increased, more cooling is needed which can be accomplished by either or both of increasing the velocity of the air and reducing the temperature of the air.

It is well known by those of ordinary skill in the art that lens forming materials having utility in the present invention tend to shrink as they cure. If the relatively thin portion of a lens is allowed to polymerize before the relatively thick portion, the relatively thin portion will tend to be rigid at the time the relatively thick portion cures and shrinks and the lens will either release prematurely from or crack the mold members 78. Accordingly, when the relative intensity of ultraviolet light incident upon the edge portion of a positive lens is reduced relative to the center portion, the center portion polymerizes faster and shrinks before the edge portion is rigid so that the shrinkage is more uniform. Conversely, when the relative intensity of ultraviolet light incident upon the center portion of a negative lens is reduced relative to the edge portion, the edge portion polymerizes faster and shrinks before the center becomes rigid so that the shrinkage is more uniform.

The variation of the relative intensity of ultraviolet light incident upon a lens may be accomplished in a variety of ways. According to one method, in the case of a positive lens, a ring of opaque material may be placed between the lamps 40 and the lens cell 52 so that the incident ultraviolet light falls mainly on the thicker center portion of the lens. Conversely, for a negative lens, a disk of opaque material may be placed between the lamps 40 and the lens cell 52 so that the incident ultraviolet light falls mainly on the edge portion of the lens.

According to another method, in the case of a negative lens, a sheet material having a variable degree of opacity ranging from opaque at a central portion to transparent at a radial outer portion is disposed between the lamps 40 and the lens cell 52. Conversely, for a positive lens, a sheet material having a variable degree of opacity ranging from transparent at a central portion to opaque at a radial outer portion is disposed between the lamps 40 and the lens cell 52.

According to still another method, a plurality of ultraviolet-light absorbing geometric or random shapes are printed and arranged on a sheet material. In the case of a positive lens, the density of the shapes is greatest at a radial outer portion while the density of the shapes is smallest at a central portion of the pattern. Conversely, in the case of a negative lens, the density of the shapes is smallest at a radial outer portion while the density of the shapes is greatest at a central portion of the pattern.

Those of ordinary skill in the art will recognize that there are a wide variety of techniques other than those enumerated above for varying the intensity of the ultraviolet light incident upon the opposed mold members 78.

The intensity of the incident light has been measured and determined to be approximately 3.0 to 5.0 milliwatts per square centimeter ($mW/cm^2$) prior to passing through either the upper light filter 54 or the lower light filter 56 and the total intensity at the thickest part of the lens ranges from 0.6 to 2.0 $mW/cm^2$ while the intensity at the thinnest portion

of the lens ranges from 0.1 to 1.5 mW/cm$^2$. It has also been determined that the overall light intensity incident on the lens cell 52 has less of an impact on the final product than the relative light intensity incident upon the thick or thin portions of the lens so long as the lens cell 52 is sufficiently cooled to reduce the polymerization rate to an acceptable level.

It has been determined that the finished power of an ultraviolet light polymerized lens may be controlled by manipulating the distribution of the incident ultraviolet light striking the opposed mold members 78. For instance, for an identical combination of mold members 78 and gasket 80, the focusing power of the produced lens may be increased or decreased by changing the pattern of intensity of ultraviolet light across the lens mold cavity 82 or the faces of the opposed mold members 78.

As the lens forming material begins to cure, it passes through a gel state, the pattern of which within the lens cell 52 leads to the proper distribution of internal stresses generated later in the cure when the lens forming material begins to shrink.

As the lens forming material shrinks during the cure, the opposed mold members 78 will flex as a result of the different amounts of shrinkage between the relatively thick and the relatively thin portions of the lens. When a negative lens, for example, is cured, the upper or back mold member 90 will flatten and the lower or front mold member 92 will steepen with most of the flexing occurring in the lower or front mold member 92. Conversely, with a positive lens, the upper or back mold member 90 will steepen and the lower or front mold member 92 will flatten with most of the flexing occurring in the upper or back mold member 90.

By varying the intensity of the ultraviolet light between the relatively thin and the relatively thick portions of the lens in the lens forming cavity 82, it is possible to create more or less total flexing. Those light conditions which result in less flexing will minimize the possibility of premature release.

The initial curvature of the opposed mold members 78 and the center thickness of the lens produced can be used to compute the theoretical or predicted power of the lens. The ultraviolet light conditions can be manipulated to alter the power of the lens to be more or less than predicted. For example, when a disk of opaque material is positioned between the lower lamp chamber 18 and the lens cell 52, less total flexure is observed. The greater the diameter of the disk of opaque material, the more negative (-) power the resultant lens will exhibit.

When the lenses cured by the ultraviolet light are removed from the opposed mold members 78, they are under a stressed condition. It has been determined that the power of the lens can be brought to a final resting power, by subjecting the lenses to a post-curing heat treatment to relieve the internal stresses developed during the cure and cause the curvature of the front and the back of the lens to shift. Typically, the lenses are cured by the ultraviolet light in about 10-30 minutes (preferably about 15 minutes). The post-curing heat treatment is conducted at approximately 85-120°C for approximately 5-15 minutes. Preferably, the post-curing heat treatment is conducted at 100-110°C for approximately 10 minutes. Prior to the post-cure, the lenses generally have a lower power than the final resting power. The post-curing heat treatment reduces yellowing of the lens and reduces stress in the lens to alter the power thereof to a final power. The post-curing heat treatment can be conducted in a conventional convection oven or any other suitable device.

The ultraviolet lamps 40 preferably are maintained at a temperature at which the lamps 40 deliver maximum output. The lamps 40, preferably, are cooled because the intensity of the light produced by the lamps 40 fluctuates when the lamps 40 are allowed to overheat. In the apparatus depicted in Fig. 2, the cooling of the lamps 40 is accomplished by sucking ambient air into the upper lamp chamber 14 and lower lamp chamber 18 through vent 32, vent chambers 34 and openings 36 by means of exhaust fans 44 and 46, respectively. Excessive cooling of the lamps 40 should be avoided, however, as the intensity of the light produced by the lamps 40 is reduced when the lamps 40 are cooled to an excessive degree.

As noted above, the lens cell 52, preferably, is cooled during curing of the lens forming material as the overall intensity of the incident ultraviolet light is increased. Cooling of the lens cell 52 generally reduces the likelihood of premature release by slowing the reaction and improving adhesion. There are also improvements in the optical quality, stress characteristics and impact resistance of the lens. Cooling of the lens cell 52 is accomplished by blowing air across the lens cell 52. The air has a temperature of between 0°C and less than 20°C. The air distribution devices 94 depicted in Fig. 5 have been found to be particularly advantageous as they are specifically designed to direct air directly across the surface of the opposed mold members 78. The air is directed to flow from the outer edges of each respective mold member 78 to the center of the respective mold member. After passing across the surface of the opposed mold members 78, the air emanating from the air distribution devices 94 is vented through vents 33. Alternatively the air emanating from the air distribution devices 94 may be recycled back to an air cooler 312, such as is shown in Figure 9.

The opposed mold members 78, preferably, are thoroughly cleaned between each curing run as any dirt or other impurity on the mold members 78 may cause premature release. The mold members 78 are cleaned by any conventional means well known to those of ordinary skill in the art such as with a domestic cleaning product i.e. "Mr. Clean"® available from Procter and Gamble. Those of ordinary skill in the art will recognize, however, that many other techniques may also be used for cleaning the mold members 78.

Yellowing of the finished lens may be related to the monomer composition, the identity of the photoinitiator and the concentration of the photoinitiator.

When casting a lens, particularly a positive lens that is thick in the center, cracking may be a problem. Addition

polymerization reactions, including photochemical addition polymerization reactions, are exothermic. During the process, a large temperature gradient may build up and resulting stress may cause the lens to crack.

When the polymerization reaction proceeds too rapidly, heat buildup inside the system which leads to cracking is inevitable. The likelihood of cracking increases as the temperature difference between the center of the lens forming material and room temperature increases. During the polymerization process, several forces tending to crack the lens, such as shrinkage, adhesion, and thermal gradients, are at work. Other forces tending to crack the lens may occur when the irradiation is stopped and the lens is cooled, especially if the lens cell 52 is allowed to cool too quickly.

The formation of optical distortions usually occurs during the early stages of the polymerization reaction during the transformation of the lens forming composition from the liquid to the gel state. Once patterns leading to optical distortions form they are difficult to eliminate. When gelation occurs there is a rapid temperature rise. The exothermic polymerization step causes a temperature increase, which in turn causes an increase in the rate of polymerization, which causes a further increase in temperature. If the heat exchange with the surroundings is not sufficient enough there will be a runaway situation that leads to premature release, the appearance of thermally caused striations and even breakage. Since the rate of polymerization increases rapidly at the gelation point, this is an important phase of the reaction.

Accordingly, it is preferred that the reaction process be smooth and not too fast but not too slow. Heat is preferably not generated by the process so fast that it cannot be exchanged with the surroundings. The incident ultraviolet light intensity preferably is adjusted to allow the reaction to proceed at a desired rate. It is also preferred that the seal between the annular gasket 80 and the opposed mold members 78 is as complete as possible.

Factors that have been found to lead to the production of lenses that are free from optical distortions are (1) achieving a good seal between the annular gasket 80 and the opposed mold members 78; (2) using mold members 78 having surfaces that are free from defects; (3) using a formulation having an appropriate type and concentration of photoinitiator that will produce a reasonable rate of temperature rise; and (4) using a homogeneous formulation. Preferably, these conditions are optimized.

Premature release of the lens from the mold will result in an incompletely cured lens and the production of lens defects. Factors that contribute to premature release are (1) a poorly assembled lens cell 52; (2) the presence of air bubbles around the sample edges; (3) imperfection in gasket lip or mold edge; (4) inappropriate formulation; (5) uncontrolled temperature rise; and (6) high or nonuniform shrinkage. Preferably, these conditions are minimized.

Premature release may also occur when the opposed mold members 78 are held too rigidly by the annular gasket 80. Preferably, there is sufficient flexibility in the annular gasket 80 to permit the opposed mold members 78 to follow the lens as it shrinks. Indeed, the lens must be allowed to shrink in diameter slightly as well as in thickness. The use of an annular gasket 80 that has a reduced degree of stickiness with the lens during and after curing is therefore desirable.

In a preferred technique for filling the lens molding cavity 82, the annular gasket 80 is placed on a concave or front mold member 92 and a convex or back mold member 90 is moved into place. The annular gasket 80 is then pulled away from the edge of the back mold member 90 at the uppermost point and a lens forming composition is injected into the lens molding cavity 82 until a small amount of the lens forming composition is forced out around the edge. The excess is then removed, preferably, by vacuum. Excess liquid that is not removed could spill over the face of the back mold member 90 and cause optical distortion in the finished lens.

Despite the above problems, the advantages offered by the radiation cured lens molding system clearly outweigh the disadvantages. The advantages of a radiation cured system include a significant reduction in energy requirements, curing time and other problems normally associated with conventional thermal systems.

The lens forming material can comprise any suitable liquid monomer or monomer mixture and any suitable photosensitive initiator. The lens forming material, preferably, does not include any component, other than a photoinitiator, that absorbs ultraviolet light having a wavelength in the range of 300 to 400 nm. The liquid lens forming material, preferably, is filtered for quality control and placed in the lens molding cavity 82 by pulling the annular gasket 80 away from one of the opposed mold members 78 and injecting the liquid lens forming material into the lens molding cavity 82. Once the lens molding cavity 82 is filled with such material, the annular gasket 80 is replaced into its sealing relation with the opposed mold members 78. The material can then be irradiated with ultraviolet light in the manner described above for a time period that is necessary to cure the lens forming material, preferably approximately 10 to approximately 30 minutes. The ultraviolet light entering the lens molding cavity 82 preferably has a wavelength in the range of approximately 300 nm. to approximately 400 nm.

Those skilled in the art will recognise that once the cured lens is removed from the lens molding cavity 82 by disassembling the opposed mold members 78, the lens can be further processed in a conventional manner, such as by grinding its peripheral edge.

Premature release may occur if the temperature rise of the lens forming composition is uncontrolled. Premature release may also occur if the opposed mold members 78 are held too rigidly by the annular gasket 80. There is preferably sufficient flexibility in the gaskets 80 to permit the mold members 78 to follow the lens as it shrinks. Insufficient sealing, unsuitable gasket material and/or a small residual amount of uncured material have also been found to contribute to premature release failures.

For best results, both the casting surfaces 86 and non-casting surfaces 88 of the mold members 78 are finished to

optical quality. For instance, a wave on the non-casting surface 88 may be reproduced in the finished lens as a result of the distortion of the incident light.

Mold markings cause differential light intensity conditions under the marking, even when the mark is on the non-casting surface 88 of the mold members 78. The fully exposed region of the lens will tend to be harder, and the lens may have stresses because of this. The portion of the lens under the mark will also tend to be weaker at the end of the curing period. This effect has been observed and may cause premature release or induce cracking.

Mold defects at the edges interfere with the sealing conditions and frequently induce premature release.

Plastic lenses may be produced by irradiating the lens forming material with ultraviolet light that is prevented from passing through the faces of the opposed mold members 78 and instead passes through the transparent or translucent wall of annular gasket 80 of the lens cell 52. By irradiating in this manner, the thicker edge portion of a negative lens receives a higher level of light intensity than the thinner center portion since the light intensity drops as it passes through the deeper layers of the lens material and glass molds. This method has a desirable advantage of allowing the application of clamping pressure to the front and back molds, which is useful in controlling premature release. This technique will be referred to as through-the-gasket irradiation.

According to the through-the-gasket irradiation technique, the annular gaskets 80, preferably, are silicone gaskets. Through continued use, however, silicone gaskets tend to become too opaque to allow sufficient ultraviolet light to pass through the gasket to complete the polymerization of the lens forming material. In addition, gaskets having a frosty appearance were observed to yield good quality lenses while gaskets that were clear were observed to yield lenses with optical distortions.

The through-the-gasket irradiation techniques make it relatively easy to exert clamping pressure on the mold members 78. Pressure (up to 206.7 $kN/m^2$ (30 psi)) may be applied to the mold members 78, preferably at or about the onset of gelation of the lens forming material, i.e. after the lens forming material is no longer liquid but before it becomes incompressible. At the beginning of the irradiation when the lens forming material is liquid, however, low clamping pressure (such as 8.88 N (2 lb.)) may be applied to the mold members 78, which pressure is not so great that the lens forming material leaks between the gasket 80 and the edges of the mold members 78. These techniques also tend to make it easier to direct evenly distributed ultraviolet light to the lens forming material. The gasket 80 serves as a diffuser and prevents sharp intensity gradients that occur when light is passing through the mold and there is an irregularity in the mold. Since the edge of a lens receives a higher intensity of ultraviolet light than the center of the lens, the through-the-gasket technique, therefore, is quite beneficial for the production of negative lenses. Finally, since ultraviolet radiation does not pass through the mold members 78 according to this technique, metal molds which are more flexible (and which tend to exhibit enhanced heat transfer properties) than glass molds can be utilized.

As discussed above, the likelihood of premature release may be affected by a number of often interrelated factors. Factors such as improper mold cleaning, mold thickness, or gasket/mold design may contribute to premature release. Other factors that may contribute to premature release may include light intensity, the chemical formulations, and the amount and identity of the photoinitiator ("PI"). As discussed above, an additional factor related to premature release is the exothermic heat generated by the reaction.

It is believed that as the reaction proceeds, the heat generated tends to reduce the adhesion between the shrinking lens and the mold face. This reduction in adhesion tends to cause the lens to pull away from the mold. In high curvature (i.e. high power) lenses this problem tends to be even more pronounced because of two factors: (1) these lenses have more thickness and thus more material that is generating heat (which thus speeds up the reaction and generates more heat), and (2) these lenses have a greater thickness differential between the thick and thin portions of the lens, which tends to cause stress on the molds due to differential shrinkage. It is also possible that the temperatures generated relatively deep inside a thick lens may cause some vaporization of the monomer. The vaporized monomer may then migrate to the lens/mold interface, breaking the vacuum between the two.

Because of the problem of premature release, preferably high power lenses are cured to maintain adhesion to the molds. Preferably the molds flex and accommodate stress.

Preferably premature release is controlled by controlling the exothermic reaction heat. This heat is controlled by directing cooling air at the mold faces. Thus in a preferred embodiment the invention includes the following steps: (1) placing a polymerizable lens forming material in a mold cavity defined in part between a first mold member and a second mold member, (2) directing ultraviolet rays towards at least one of the first or second mold members, and (3) cooling the first mold member and the second mold member with air. In a preferred embodiment the ultraviolet rays are directed towards the mold member(s) while the first and second mold members are cooled. The above steps may be carried out with an apparatus for making a plastic lens that includes: (1) a first mold member, (2) a second mold member spaced apart from the first mold member, the first and second mold members defining a mold cavity, (3) an ultraviolet light generator for generating and directing ultraviolet light toward at least one of the first and second mold members during use, (4) an ultraviolet light filter disposed between the ultraviolet light generator and the first mold member, and between the ultraviolet light generator and the second mold member, and (5) a distributor for directing cooling air to the mold members during use.

Both the first and second mold members are "directly" cooled by the air. That is, the face of the first mold member

and the face of the second mold member is cooled by directing air towards the face of both of the mold members. The "face" of the mold members is the outer mold surface that is not contacting either the gasket or the lens forming materials (see Fig. 6). The air may be directed at various angles towards the face of the mold members.

The air is directed from the edges of the mold member faces to the center of the mold member faces. In this manner the air that contacts the edges of the mold members is approximately the same temperature at all the edges of the mold members, and approximately the same at all radii from the center of the mold members (with some variances due to variances in the cavity thickness at certain radii). Thus substantially the same thicknesses of the lens material are subjected to air that is substantially the same temperature, resulting in a more even cooling of the lens material. Generally less favorable results are achieved if air is simply directed across the mold members since the air temperature and flow rate at the first edge contacted by the air may be somewhat different than the air temperature and flow rate at the second mold member edge. Specifically, if cooling air is passed over the lens forming material in one direction only, the side opposite the source of air tends to remain hotter because the air passing over it has picked up the heat from the first side.

The fluid is air at a temperature of between 0°C and less than 20°C, preferably about 0-15°C, more preferably about 0-10°C, more preferably still about 3-8°C. In one preferred embodiment the air temperature was about 5°C. As shown in Figure 7, a lens forming apparatus 300 for making a plastic lens may include a cooler 312 for supplying cool air to the apparatus 300 via conduit 314. The air may be supplied to the apparatus 300 and then discharged via conduit 320. The air discharged via conduit 320 may be vented via conduit 318 or it may alternately be recirculated via conduit 316 to the cooler 312. The cooler 312 preferably includes a Neslab CFT-50 water/antifreeze chiller (Newington, N.H., U.S.A.). A Neslab-built blower box designed for a minimum temperature of 3°C and 8 cubic feet (about 0.224 cubic meters) per minute of air per air distributor 94 was used with the chiller. The blower box included a heat exchanger coil through which chilled water was circulated, a blower, and a plenum-type arrangement for supplying air to the conduit 314. The remaining components of Figure 7 are described in more detail below.

Certain lenses may be made by controlling (e.g., cooling) the temperature of the lens material during cure with circulating uncooled air (i.e., air at ambient temperatures), the air having a temperature of less than 20°C The ambient air in these systems is directed towards the mold members in the same manner as described above. Circulating ambient temperature air permits manufacture of a wider range of prescriptions than manufacture of the lenses without any mold cooling at all. For instance, if the temperature of the circulating air is held at slightly less than room temperature (about 19°C), prescriptions from +2 to -3 diopter may be successfully cast. Higher diopters, either + or -, often tend to fail without circulating cooled fluid.

Most polymerization factors are interrelated. The ideal temperature of polymerization is related to the diopter and thickness of the lens being cast. Thermal mass is a factor. Lower temperatures (below about 10°C) are preferred to cast higher + or - diopter lenses. These lower temperatures tend to permit an increase in photoinitiator concentration, which in turn may speed up the reaction and lower curing time.

Preventing premature release is also somewhat dependent upon the flowrates of cooling air, as well as its temperature. For instance, if the temperature of the cooling air is decreased it may also be possible to decrease the flowrate of cooling air. Similarly, the disadvantages of a higher temperature cooling air may be somewhat offset by higher flowrates of cooling air.

In one embodiment the air flow rates for a dual distributor system (i.e., an air distributor above and below the lens composition) are about 1-30 standard cubic feet (about 0.028 - 0.850 standard cubic meters) per minute per distributor, more preferably about 4-20 cubic feet (about 0.113-0.566 standard cubic meters) per minute per distributor, and more preferably still about 9-15 (about 0.255-0.423 standard cubic meters) cubic feet per minute per distributor. "Standard conditions," as used herein, means 60°F (about 15.556°C) and one atmosphere pressure (about 101.325 kilopascals).

In a preferred embodiment the air distributor 94 may include 30 substantially evenly spaced orifices 98 disposed to allow air to be directed from the distributor 94 to the mold members. In a preferred embodiment the diameter of fifteen orifices 98 on the one-half of the cylindrical opening 96 closest the plenum portion 95 is about 1/4 inch (about 6.35 mm), and the cumulative volume flowrate of air through such orifices is estimated to be about 6.10 standard cubic feet (about 0.173 standard cubic meters) per minute. In the same embodiment the diameter of fifteen orifices 98 on one-half of the cylindrical opening 96 opposite the plenum portion 95 is about 5/16 inch (about 7.94 mm), and the cumulative volume flowrate of air through such orifices is estimated to be about 8.30 standard cubic feet (about 0.235 standard cubic meters) per minute. Thus the total flowrate for one distributor is estimated to be about 14.40 standard cubic feet (about 0.408 standard cubic meters) per minute, and the total flowrate for two distributors is estimated to be about 28.80 standard cubic feet (about 0.816 standard cubic meters) per minute.

In the same embodiment the edge of the orifices 98 in the cylindrical opening 96 are tapered out. In such case the cumulative flowrates for the 1/4 inch (6.35 mm) orifices 98 is estimated to be about 5.89 standard cubic feet (about 0.167 standard cubic meters) per minute, and the flowrate for the 5/16 inch (7.94 mm) orifices 98 is estimated to be about 7.02 standard cubic feet (about 0.199 standard cubic meters) per minute. Thus the total flowrate for one distributor is estimated to be about 12.91 standard cubic feet (about 0.366 standard cubic meters) per minute, and the total flowrate for two distributors is estimated to be about 25.82 standard cubic feet (about 0.731 standard cubic meters) per

minute.

In an alternate preferred embodiment the diameter of fifteen orifices 98 on the one-half of the cylindrical opening 96 closest to the plenum portion 95 are about 3/16 inch (about 4.76 mm), and the cumulative volume flowrate of air through such orifices is estimated to be about 3.47 standard cubic feet (about 0.98 standard cubic meters) per minute. In the same embodiment the diameter of fifteen orifices 98 on the one-half of the cylindrical opening 96 opposite the plenum portion 95 are about 1/4 inch (about 6.35 mm), and the cumulative volume flowrate of air through such orifices is estimated to be about 6.17 standard cubic feet (about 0.175 standard cubic meters) per minute. Thus the total flowrate for one distributor is estimated to be about 9.64 standard cubic feet (about 0.273 standard cubic meters) per minute, and the total flowrate for two distributors is estimated to be about 19.28 standard cubic feet (about 0.546 standard cubic meters) per minute.

Actual flowrates through individual orifices 98 tended to vary. The flowrates through the orifices 98 that were closest to or most opposite the plenum portion 95 of air distribution device 94 tended to have a flowrate that is greater than orifices in between these orifices. These higher flowrates varied up to approximately 1.2-2.5 times the flowrate of orifices that were in between the closest to and most opposite orifices.

The above estimated flowrates for orifices 98 in a preferred embodiment were calculated using a bench model of air distributor 94 connected to air flowrate measuring devices. The air flowrates for the orifices 98 in the bench model were measured. The total air flowrate through the bench model distributor 94 was measured. The total air flowrate for a preferred embodiment distributor 94 was measured. The above flowrates were measured by measuring the average velocity across a cross-sectional area, and then multiplying such velocity by the cross-sectional area. The estimated flowrates for the preferred embodiment orifices 98 were obtained by the following equation:

$$P_o = B_o \times (P_A/B_A),$$

where

$P_o$ = estimated preferred embodiment orifices 98 flowrate,
$P_A$ = measured preferred embodiment distributor 94 flowrate,
$B_o$ = measured bench orifices 98 flowrate, and
$B_A$ = measured bench distributor 94 flowrate.

To minimize premature release and produce water-white ophthalmic lenses, preferably a lens is initially cured as described above. That is, a lens forming material is preferably initially cured at relatively low temperatures, relatively low ultraviolet light intensity, and relatively low photoinitiator concentrations. "Initial" or "first" cure means the cure that transforms the liquid lens forming material into a solid material. Lenses produced as such generally have a Shore D hardness of about 60-78 (for the preferred compositions) when cured for about 15 minutes as described above. The hardness may be improved to about 80-81 Shore D by postcure heating the lens in a conventional oven for about 10 minutes, as described above. In the initial cure it is difficult to raise the hardness and surface cure of ultraviolet cured lenses above the levels described above. Achieving a higher degree of hardness and cure generally requires a faster, hotter reaction. The faster, hotter initial cure reaction, however, tends to lead to poorer yields and lessened lens optical quality.

In a preferred embodiment of the invention, factors such as the level of cure, rigidity, and hardness of ultraviolet light polymerized lenses may be improved. A method of the invention to improve these factors involves making a lens as described above, demolding the lens, and then subjecting the lens to relatively high intensity ultraviolet light postcure conditions. This method may be carried out using a system partially shown in Figure 7 including: an apparatus 300 for making a plastic lens which includes a first mold member, a second mold member spaced apart from the first mold member, and the first and second mold members defining a mold cavity, a first ultraviolet light generator for generating and directing ultraviolet light towards at least one of the first and second mold members during use, an ultraviolet light filter disposed between the first ultraviolet light generator and the first mold member, and between the first ultraviolet light generator and the second mold member, and a distributor for directing cooling air towards the first and second mold members during use; a second ultraviolet light generator 304 for generating and directing ultraviolet light towards the lens during use; and a first heater 306 to heat the lens during use. The system may also include a third ultraviolet light generator 308 for generating and directing ultraviolet light towards the lens during use after the lens has been heated. The system may also include a second heater 310 for heating the lens during use after the third ultraviolet light generator has directed light towards the lens. The system may also include a demolder 302, which may simply include a small hammer and chisel.

In a preferred embodiment the second and third ultraviolet light generators are the same generator. In a preferred embodiment the first and second heaters are the same heater. In a preferred embodiment the first and second heater may be incorporated with the second and third UV light generators. The system may also include additional heaters and or UV light generators.

Preferably the second and/or third ultraviolet light generators provide ultraviolet light at an intensity of about 150-300 mW/cm$^2$, more preferably about 175-250 mW/cm$^2$, at a wavelength range of about 360-370 nm (preferably about 365nm). Preferably the second and/or third ultraviolet light generators provide ultraviolet light at an intensity of about 50-150 mW/cm$^2$, more preferably about 75-125 mW/cm$^2$, at a wavelength range of about 250-260 nm (preferably about 254 nm). The first or initial ultraviolet light generator preferably provides ultraviolet light at a total intensity (from both sides) of less than 10 mW/cm$^2$ (preferably about 0.3-2.0 mW/cm$^2$). Thus preferably the second or third ultraviolet light generators provide at least about 2, 5, 10, 20, 40, 100, 500, 1000, and/or 1800 times the intensity of ultraviolet light than is provided by the first ultraviolet light generator. Preferably these generators provide about 40-100, 100-500, 500-1800, 100-1800, and/or 40-1800 times the amount of light provided by the first ultraviolet light generator. Preferably the lens is exposed to the ultraviolet light in the second, third and/or subsequent ultraviolet light generators for less than about 5 minutes, more preferably less than 1.0 minute, and more preferably still less than about 30 seconds. Preferably this exposure time is about 0.1-300 seconds, more preferably about 0.1-60 seconds, and more preferably still about 0.1-30 seconds. In another preferred embodiment the exposure time was less than 5 minutes. Generally as the intensity of the light is increased, the exposure time may be decreased, and vice versa.

Preferably the lens is heated in the first or second heaters for less than about 180 minutes, more preferably less than 30 minutes, and more preferably still less than about 10 minutes. Preferably the lens is heated in the second and/or third heaters at a temperature of about 65-180°C, more preferably about 85-140°C, and more preferably still about 100-120°C. Generally as the temperature is decreased, the amount of heating time should be increased, and vice versa. In another preferred embodiment the heating time was less than 5 seconds.

The lens is preferably cleaned (e.g., in a 50 volume % methanol/water solution) prior to exposing the lens to the relatively high intensity light. The relatively high intensity light may include relatively long and/or short wavelengths. The lens may then be heated. The lens may be repeatedly exposed to relatively high intensity ultraviolet light. The lens may be repeatedly heated.

In a preferred embodiment, the high intensity light may be provided with mercury vapor lamps provided in a UVEXS, Inc. Model CCU curing chamber (Sunnyvale, CA, U.S.A.).

It is believed that shorter wavelengths tend to improve the extent of surface cure and that longer wavelengths tend to increase the extent of cure within the middle portions of the lens. Thus it is preferably to use both shorter and longer ultraviolet light wavelengths for the second and third ultraviolet light generators. Exposure to the relatively high intensity UV wavelengths tends to yellow the lens, however subsequently heating the lens tends to reduce and/or eliminate this yellowing. Preferably the lens is heated to about 110-120°C. Heating also allows radicals to terminate and tends to increase the crosslinking of the compounds within the lens. The polymerization strain also tends to be reduced during heating.

Lenses cured according to the above procedure exhibited a Shore D hardness of above 83, with most lens about 83-85. These lenses also were more rigid and tended to warp less when inserted into an eyeglass frame after edging. There was negligible difference in the impact resistance and scratch resistance of the lenses cured in this fashion, compared to lenses cured without exposure to the relatively high intensity UV light. It is anticipated that the postcure methods described above will tend to remedy lesser defects that may occur in the first cure using the first UV light generator. For instance, the cure level for relatively low mass lenses during the first cure may be less important since the postcure will tend to ensure that the lenses are adequately cured. In like manner, different lens compositions that do not cure to form ophthalmic quality lenses in the first cure may be now usable since the postcure method may increase the quality of the cured lenses. For instance, the amount of photointiator and/or stabilizers in the initial composition may be varied over a broader range and still achieve acceptable water-white lenses.

In an alternate method for making a lens, the desired curvature (i.e., power) of the lens may be varied using the same molds, but with different light distributions. In this manner one mold may be used to prepare different lenses with different curvatures. The method includes the steps of: (1) placing a polymerizable lens forming material in a mold cavity defined in part between a first mold member and a second mold member, and wherein the cavity defines a theoretical curvature that is different from the desired curvature, (2) directing ultraviolet rays towards at least one of the first and second mold members, and wherein the ultraviolet rays are directed towards the first or second mold member such that the material cures to form a lens with the desired curvature, and (3) contacting air against the first or second mold member to cool the first or second mold member. The resulting lens curvature may vary depending on the way the ultraviolet light is directed towards the first or second mold members. That is, by varying the relative intensity of the light across the lens material radii, it is possible to vary the curvature of the resulting lens.

Lens curvatures may also vary when the lenses are subjected to postcure heating. Thus the curvature of the lenses may be varied by exposing the lens material to UV light, and then demolding and heating the lens. The heating may then result in the desired curvature, and this curvature may be different from the theoretical curvature expected from the dimensions of the mold cavity, as well as the curvature obtained after the lens has been exposed to the initial UV light.

The present invention will now be described in more detail with reference to the following examples. These examples are merely illustrative of the present invention and are not intended to be limiting.

EXAMPLE 1 - REDUCED TEMPERATURE CURING

Formulation:

| | |
|---|---|
| 17% | Bisphenol A BisAllyl Carbonate |
| 10% | 1,6 Hexanediol dimethacrylate |
| 20% | Trimethylolpropane triacrylate |
| 21% | Tetraethyleneglycol diacrlate |
| 32% | Tripropyleneglycol diacrlyate |
| 0.012% | 1 Hydroxycyclohexyl phenyl ketone |
| 0.048 | Methylbenzoylformate |
| <10PPM | Hydroquinone & Methylethylhydroquinone |

Hydroquinone and Methylethylhydroquinone were stabilizers present in some of the diacrylate and/or triacrylate compounds obtained from Sartomer. Preferably the amount of stabilizers is minimized since the stabilizers affect the rate and amount of curing. If larger amounts of stabilizers are added, then generally larger amounts of photoinitiators must also be added.

Light Condition: mW/cm$^2$ measured at plane of sample

| | Center | Edge |
|---|---|---|
| Top: | 0.233 | 0.299 |
| Bottom: | 0.217 | 0.248 |

Air Flow: 0.26 standard cubic metres per minute (CMM) (9.6 standard cubic feet per minute ("CFM")) per manifold / 0.53 CMM (19.2 CFM) total on sample

Air Temperature: 4.4 degrees Centigrade

Molds: 80 mm diameter Corning #8092 glass

| | Radius | Thickness |
|---|---|---|
| Concave: | 170.59 | 2.7 |
| Convex: | 62.17 | 5.4 |

Gasket: General Electric SE6035 silicone rubber with a 3 mm thick lateral lip dimension and a vertical lip dimension sufficient to provide an initial cavity center thickness of 2.2 mm.

Filling: The molds were cleaned and assembled into the gasket. The mold/gasket assembly was then temporarily positioned on a fixture which held the two molds pressed against the gasket lip with about 1 kg. of pressure. The upper edge of the gasket was peeled back to allow about 27.4 grams of the monomer blend to be charged into the cavity. The upper edge of the gasket was then eased back

into place and the excess monomer was vacuumed out with a small aspirating device. It is preferable to avoid having monomer drip onto the noncasting surface of the mold because a drop tends to cause the ultraviolet light to become locally focused and may cause an optical distortion in the final product.

Curing: The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber. The molds were separated from the cured lens by applying a sharp impact to the junction of the lens and the convex mold. The sample was then postcured at 110 °C in a conventional gravity type thermal oven for an additional ten minutes, removed and allowed to cool to room temperature.

Results: The resulting lens measured 72 mm in diameter, with a central thickness of 2.0 mm, and an edge thickness of 9.2 mm. The focusing power measured ~5.05 diopter. The lens was water clear ("water-white"), showed negligible haze, exhibited total visible light transmission of about 94%, and gave good overall optics. The Shore D hardness was about 80. The sample withstood the impact of a 2.54 cm (1 inch) steel ball dropped from 127 cm (fifty inches) in accordance with ANSI 280.1-1987, 4.6.4 test procedures.

## EXAMPLE 2 - REDUCED TEMPERATURE CURING

Formulation:

| | |
|---|---|
| 17% | Bisphenol A BisAllyl Carbonate |
| 10% | 1,6 Hexanediol dimethacrylate |
| 20% | Trimethylolpropane triacrylate |
| 21% | Tetraethyleneglycol diacrlate |
| 32% | Tripropyleneglycol diacrlyate |
| 0.012% | 1 Hydroxycyclohexyl phenyl ketone |
| 0.048% | Methylbenzoylformate |
| <10PPM | Hydroquinone & Methylethylhydroquinone |

Light Condition: mW/cm$^2$ measured at plane of sample

| | Center | Edge |
|---|---|---|
| Top: | 0.251 | 0.330 |
| Bottom: | 0.236 | 0.265 |

Air Flow: 0.26 CMM (9.6 CFM) per manifold / 0.53 CMM (19.2 CFM) total on sample

Air temperature: 4.4 degrees Centigrade

Molds: 80 mm dia. Corning #8092 glass

| | Radius | Thickness |
|---|---|---|
| Concave: | 113.28 | 3.2 |
| Convex: | 78.64 | 5.5 |

Gasket: General Electric SE6035 silicone rubber with a 3 mm thick lateral lip dimension and a vertical lip dimension sufficient to provide a initial cavity center thickness of 1.9 mm.

Filling: The molds were cleaned and assembled into the gasket. The mold/gasket assembly was them temporarily positioned on fixture which held the two molds pressed against the gasket lip with about 1 kg. of pressure. The upper edge of the gasket was peeled back to allow about 15.1 grams of the monomer blend to be charged into the cavity. The upper edge of the gasket was then eased back into place and the excess monomer was vacuumed out with a small aspirating device. It is preferable to avoid having monomer drip onto the noncasting surface of the mold because a drop will cause the ultraviolet light to become locally focused too strongly on the monomer in the cavity and may cause an optical distortion in the final product.

Curing: The sample was irradiated for fifteen minutes under the above conditions and removed from the curing chamber. The molds were separated from the cured lens by applying a sharp impact to the junction of the lens and the convex mold. the sample was then postcured at 110 degrees C in a conventional gravity type thermal oven for an additional ten minutes, removed and allowed to cool to room temperature.

Results: The resulting lens measured 73 mm in diameter, with a central thickness of 1.7 mm, and an edge thickness of 4.3 mm. The focusing power measured ~1.90 diopters. The lens was water clear, showed no haze, exhibited total visible light transmission of 94%, and gave good overall optics. The Shore D hardness was 81. The sample withstood the impact of a 2.22 cm (7/8 inch) steel ball dropped from 127 cm (fifty inches) in accordance with ANSI 280.1-1987, 4.6.4 test procedure.

## Claims

1. A method for making a plastic lens, comprising: placing a polymerizable lens forming material in a mold cavity (82) defined between a first mold member (78) with a face (86), and a second mold member (78) with a face (86) and a gasket (80); and directing ultraviolet rays (40) towards at least one of the first or second mold members or said gasket while substantially simultaneously cooling the first mold member and the second mold member characterised in that the cooling is effected by directing air at a temperature of between 0°C and less than 20°C towards the faces of the first and second mold members, the air being directed from the edges of the first mold member to the center of the first mold member, and from the edges of the second mold member to the center of the second mold member.

2. The method of claim 1 wherein the air temperature is about 0-15°C.

3. The method of any of the above claims wherein the air temperature is about 0-10°C.

4. The method of any of the above claims wherein the air temperature is about 3-8°C.

5. The method of any of the above claims wherein the mold cavity (82) is substantially cylindrical and the height of the cavity varies across the diameter of the cavity; and wherein the intensity of the ultraviolet rays is varied approximately in proportion to the height of the cavity.

6. The method of any of the above claims, further comprising directing air at a rate of about 0.028-0.850 standard cubic meters (1-30 standard cubic feet) per minute toward the first mold member to cool the first mold member, and directing air at a rate of about 0.028-0.850 standard cubic meters (1-30 standard cubic feet) per minute toward the second mold member to cool the second mold member.

7. The method of claim 6 wherein the rate of air contacting the first mold member is about 0.113-0.566 standard cubic meters (4-20 standard cubic feet) per minute, and the rate of air contacting the second mold member is about 0.113-0.566 standard cubic meters (4-20 standard feet) per minute.

8. The method of claim 6 wherein the rate of air contacting the first mold member is about 0.255-0.423 standard cub meters (9-15 standard cub feet) per minute, and the rate of air contacting the second mold member is about 0.255-0.423 standard cubic meters (9-15 standard cubic feet) per minute.

9. The method of any of the above claims wherein the mold cavity is defined in part between a first mold member (78) with a thickness of about 1.0-50 mm and a second mold member (78) with a thickness of about 1.0-5.0 mm.

10. The method of claim 9 wherein the first or second mold member (78) has a thickness of about 2.0-4.0 mm.

11. The method of claim 9 wherein the first or second mold member (78) has a thickness of about 2.5-3.5 mm.

12. The method of any of the above claims wherein the polymerizable lens forming material is placed in a mold cavity defined in part between the first mold member and a second mold member separated by an annular gasket, and wherein rays of ultraviolet light are directed through the annular gasket to cure the lens forming material.

13. The method of claim 12, further comprising preventing rays of ultraviolet light from impinging against the first or second mold members.

14. A method according to any one of claims 1-11 for making a plastic lens with a desired curvature, wherein the cavity defines a theoretical curvature that is different from the desired curvature; and wherein said ultraviolet rays are directed towards at least one of the first and second mold members so that portions of the material in the cavity receive different intensities of ultraviolet light from other portions of the material in the cavity, thereby allowing the material to form a lens with the desired curvature.

15. The method of claim 14, further comprising demolding the lens, and heating the lens.

16. The method of claim 15 wherein the heating forms the lens with the desired curvature.

17. The method of any one of claims 14-16 wherein the intensity of the ultraviolet rays is varied across the first or second mold members such that the material cures to form the lens with the desired curvature.

18. The method of any claim 1-11 or 14-17, wherein the ultraviolet rays are directed at a total intensity of less than about 10 mW/cm$^2$ toward at least one of the mold members to cure the material to form a lens, and further comprising demolding the lens following said cooling step and subsequently directing a second set of ultraviolet rays at the lens at an intensity of about 150-300 mW/cm$^2$ at a wavelength range of about 360-370 nm, and about 50-150 mW/cm$^2$ at a wavelength range of about 250-260 nm.

19. The method of claim 18, further comprising directing a third set of ultraviolet rays towards the lens.

20. The method of claim 19, further comprising heating the lens after the third set of ultraviolet rays are directed towards the lens.

21. The method of claim 20 wherein the lens is heated to a temperature of about 65-180°C.

22. The method of claim 20-21 wherein the lens is heated for less than about 30 minutes.

23. The method of any one of claims 19-22 wherein the second set of ultraviolet rays are directed at a lens for less than about 1 minute.

24. The method of claim 19 or any claim dependant thereon wherein the intensity of the third set of ultraviolet rays is about 150-300 mW/cm$^2$ at a wavelength range of about 360-370 nm, and about 50-150 mW/cm$^2$ at a wavelength range of about 250-260 nm.

25. The method of claim 19 or any claim dependant thereon wherein the third set of ultraviolet rays are directed at the lens for less than about 1 minute.

26. The method of claim 20 or any claim dependant thereon wherein the lens is heated for less than about 30 minutes after the third set of ultraviolet rays are directed towards the lens.

27. Apparatus for making a plastic lens, comprising: a first mold member (78); a second mold member (78) spaced apart from the first mold member (78), the first and second mold members each having face (86) and defining a mold cavity (82); an ultraviolet light generator (40) for generating and directing ultraviolet light toward at least one of the first and second mold members during use; an ultraviolet light filter (54) disposed between the ultraviolet light generator and the first mold member and between the ultraviolet light generator and the second mold member; characterised in that the apparatus further comprises a distributor (94) adapted to direct air at a temperature of between 0°C and less than 20°C toward the first and second mold members while the ultraviolet light is substantially simultaneously directed towards at least one of the first and second mold members during use, the distributor being connected to distribute air during use from the edges of the first mold member to the center of the first mold member, and from the edges of the second mold member to the center of the second mold member.

28. The apparatus of claim 27 wherein the air temperature is about 0-15°C.

29. The apparatus of claim 28 wherein the air temperature is about 0-10°C.

30. The apparatus of claim 29 wherein the air temperature is about 3-8°C.

31. The apparatus of any one of claims 27-30 wherein the mold cavity is cylindrical and the height of the cavity varies across the diameter of the cavity.

32. The apparatus of any one of claims 27-31 wherein the filter (54) is positioned to direct ultraviolet light during use with an intensity that varies in proportion to the height of the cavity.

33. The apparatus of any one of claims 27-32 wherein the filter (54) comprises a disk of opaque material for reducing the intensity of ultraviolet light reaching the center of the mold members relative to the intensity of ultraviolet light reaching the the edge of the mold members during use.

34. The apparatus of any one of claims 27-33 wherein the filter (54) comprises a ring of opaque material for reducing the intensity of ultraviolet light reaching the edge of the mold members relative to the intensity of ultraviolet light reaching the center of the mold members during use.

35. The apparatus of any one of claims 27-34 wherein the filter (54) comprises a transparent sheet material having a plurality of ultraviolet light absolving shapes printed thereon.

36. The apparatus of claim 35 wherein the density per unit area of the shapes is at a minimum at a point corresponding to the greatest distance between the first mold member (78) and the second mold member (78) and wherein the density per unit area of the shapes is at a maximum at a point corresponding to the smallest distance between the first mold member and the second mold member.

37. The apparatus of any one of claims 27-36 wherein the distributor (94) comprises an air jet having a substantially cylindrical bore (96), and the bore has a plurality of openings (98) disposed about the circumference thereof.

38. The apparatus of claim 37 wherein the average diameter of the openings (98) in the air jet varies about the circumference of the bore (96).

39. The apparatus of any one of claims 37 or 38 wherein the air jet comprises an air inlet and the diameter of the openings (98) is at a minimum adjacent the air inlet (12), and the diameter of the openings is at a maximum at a point along the circumference of the bore that is opposite the bores having minimum diameter.

40. The apparatus of any one of claims 27-39 wherein the distributor (94) is adapted to direct during use about 0.028-0.850 standard cub meters (1-30 standard cubic feet) per minute toward the first mold member (78) to cool the first mold member, and about 0.038-0.850 standard cubic meters (30 standard cubic feet) per minute toward the second mold member (78) to cool the second mold member.

41. The apparatus of claim 40 wherein the distributor (94) is adaptable to direct during use about 0.113-0.566 standard cub meters (4-20 standard cubic feet) per minute towards the first mold member (78) to cool the first mold member,

and about 0.113-0.566 standard cubic meters (4-20 standard cubic feet) per minute towards the second mold member (78) to cool the second mold member.

42. The apparatus of claim 40 wherein the distributor (94) is adaptable to direct during use about 0.255-0.423 standard cubic meters (9-15 standard cubic feet) per minute towards the first mold member to cool the first mold member (78) and about 0.255-0.423 standard cubic meters (9-15 standard cubic feet) per minute towards the second mold member (78) to cool the second mold member.

43. The apparatus of any one of claims 27-42 wherein the first and second mold members (78) each have a thickness of less than about 5.0 mm.

44. The apparatus of claim 43 wherein the mold members (78) have a thickness of about 2.0-4.0 mm.

45. The apparatus of claim 43 wherein the mold members (78) have a thickness of about 2.5-3.5 mm.

46. The apparatus of any one of claims 27-45, further comprising a second ultraviolet light generator (304) for generating and directing ultraviolet light towards the lens during use, and a first heater (306) to heat the lens during use.

47. The apparatus of claim 46, further comprising a third ultraviolet light generator (308) for generating and directing ultraviolet light against the lens during use after the lens has been heated.

48. The apparatus of claim 47, further comprising a second heater (310) to heat the lens during use after the third ultraviolet light generator (308) has directed light against the lens.

**Patentansprüche**

1. Verfahren zum Herstellen einer Kunststofflinse, umfassend: Anordnen eines polymerisierbaren linsenbildenden Materials in einem Formenhohlraum (82), festgelegt zwischen einem ersten Formglied (78) mit einer Fläche (86) und einem zweiten Formglied (78) mit einer Fläche (86) und einer Dichtung (80); und Richten ultravioletter Strahlen (40) auf das erste Formglied, das zweite Formglied und/oder die Dichtung, während eines simultanen Kühlens des ersten Formglieds und des zweiten Formglieds, dadurch gekennzeichnet, daß das Kühlen durch Richten von Luft mit einer Temperatur von zwischen 0 °C und weniger als 20 °C auf die Flächen des ersten und zweiten Formglieds bewirkt wird, wobei die Luft von den Kanten des ersten Formglieds in die Mitte des ersten Formglieds und von den Kanten des zweiten Formglieds in die Mitte des zweiten Formglieds geführt wird.

2. Verfahren nach Anspruch 2, dadurch gekennzeichnet, daß die Lufttemperatur ungefähr 0 bis 15 °C beträgt.

3. Verfahren nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß die Lufttemperatur ungefähr 0 bis 10 °C beträgt.

4. Verfahren nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß die Lufttemperatur ungefähr 3 bis 8 °C beträgt.

5. Verfahren nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß der Formenhohlraum (82) im wesentlichen zylindrisch ist, und die Höhe des Hohlraums über den Durchmesser des Hohlraums variiert; und daß die Intensität der ultravioletten Strahlen ungefähr proportional zu der Höhe des Hohlraums variiert wird.

6. Verfahren nach einem der vorangehenden Ansprüche, ferner gekennzeichnet durch Richten von Luft mit einer Rate von ungefähr 0,028 bis 0,850 Standardkubikmeter (1 bis 30 Standardkubikfuß) pro Minute auf das erste Formglied, um das erste Formglied zu kühlen, und Richten von Luft mit einer Rate von ungefähr 0,028 bis 0,850 Standardkubikmeter (1 bis 30 Standardkubikfuß) pro Minute auf das zweite Formglied, um das zweite Formglied zu kühlen.

7. Verfahren nach Anspruch 6, dadurch gekennzeichnet, daß die Rate der Luft, die das erste Formglied kontaktiert, ungefähr 0,113 bis 0,566 Standardkubikmeter (4 bis 20 Standardkubikfuß) pro Minute beträgt, und die Rate der Luft, die das zweite Formglied kontaktiert, ungefähr 0,113 bis 0,566 Standardkubikmeter (4 bis 20 Standardfuß) pro Minute beträgt.

8. Verfahren nach Anspruch 6, dadurch gekennzeichnet, daß die Rate der Luft, die das erste Formglied kontaktiert, ungefähr 0,255 bis 0,423 Standardkubikmeter (9 bis 15 Standardkubikfuß) pro Minute beträgt, und die Rate der

Luft, die das zweite Formglied kontaktiert, ungefähr 0,255 bis 0,423 Standardkubikmeter (9 bis 15 Standardkubikfuß) pro Minute beträgt.

9. Verfahren nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß der Formenhohlraum zum Teil zwischen einem ersten Formglied (78) mit einer Dicke von ungefähr 1,0 bis 50 mm und einem zweiten Formglied (78) mit einer Dicke von ungefähr 1,0-5,0 mm festgelegt wird.

10. Verfahren nach Anspruch 9, dadurch gekennzeichnet, daß das erste oder zweite Formglied (78) eine Dicke von ungefähr 2,0 bis 4,0 mm aufweist.

11. Verfahren nach Anspruch 9, dadurch gekennzeichnet, daß das erste oder zweite Formglied (78) eine Dicke von ungefähr 2,5 bis 3,5 mm aufweist.

12. Verfahren nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß das polymerisierbare Linsenbildungsmaterial in einen Formenhohlraum plaziert wird, der zum Teil zwischen dem ersten Formglied und einem zweiten Formglied festgelegt ist, die durch eine ringförmige Dichtung voneinander getrennt sind, und daß die Strahlen des ultravioletten Lichts durch die ringförmige Dichtung geführt werden, um das Linsenbildungsmaterial auszuhärten.

13. Verfahren nach Anspruch 12, ferner gekennzeichnet durch Verhindern, daß Strahlen des ultravioletten Lichts auf das erste oder zweite Formglied auftreffen.

14. Verfahren nach einem der Ansprüche 1 bis 11 zum Herstellen einer Kunststofflinse mit einer gewünschten Krümmung, dadurch gekennzeichnet, daß der Hohlraum eine theoretische Krümmung festlegt, die sich von der gewünschten Krümmung unterscheidet, und daß besagte ultravioletten Strahlen auf das erste und/oder das zweite Formglied gerichtet werden, so daß Teile des Materials in dem Hohlraum unterschiedliche Intensitäten an ultraviolettem Licht von unterschiedlichen Bereichen des Materials in dem Hohlraum empfangen, wodurch dem Material ermöglicht wird, eine Linse mit der gewünschten Krümmung zu bilden.

15. Verfahren nach Anspruch 14, ferner gekennzeichnet durch Entformen der Linsen und Aufwärmen der Linse.

16. Verfahren nach Anspruch 15, dadurch gekennzeichnet, daß das Aufwärmen die Linse mit der gewünschten Krümmung bildet.

17. Verfahren nach irgendeinem der Ansprüche 14 bis 16, dadurch gekennzeichnet, daß die Intensität der ultravioletten Strahlen über das erste oder zweite Formglied variiert wird, so daß das Material ausgehärtet wird, um die Linse mit der gewünschten Krümmung zu bilden.

18. Verfahren nach einem der Ansprüche 1 bis 11 oder 14 bis 17, dadurch gekennzeichnet, daß die ultravioletten Strahlen mit einer Gesamtintensität von weniger als ungefähr 10 mW/cm$^2$ auf zumindest eines der Formglieder gerichtet wird, um das Material auszuhärten, um eine Linse zu bilden, und ferner umfaßt ist, die Linse zu entformen, folgend besagtem Kühlschritt, und anschließend einen zweiten Satz an ultravioletten Strahlen auf die Linse mit einer Intensität von ungefähr 150 bis 300 mW/cm$^2$ in einem Wellenlängenbereich von ungefähr 360 bis 370 nm und ungefähr 50 bis 150 mW/cm$^2$ in einem Wellenlängenbereich von ungefähr 250 bis 260 nm zu richten.

19. Verfahren nach Anspruch 18, ferner gekennzeichnet durch Richten eines dritten Satzes an ultravioletten Strahlen auf die Linse.

20. Verfahren nach Anspruch 19, ferner gekennzeichnet durch Erwärmen der Linse, nachdem der dritte Satz an ultravioletten Strahlen auf die Linse gerichtet worden ist.

21. Verfahren nach Anspruch 20, dadurch gekennzeichnet, daß die Linse auf eine Temperatur von ungefähr 65 bis 180 °C aufgewärmt wird.

22. Verfahren nach Anspruch 20 bis 21, dadurch gekennzeichnet, daß die Linse für weniger als ungefähr 30 Minuten aufgewärmt wird.

23. Verfahren nach einem der Ansprüche 19 bis 22, dadurch gekennzeichnet, daß der zweite Satz an ultravioletten Strahlen auf eine Linse für weniger als ungefähr eine Minute gerichtet wird.

24. Verfahren nach Anspruch 19 oder einem davon abhängigen Anspruch, dadurch gekennzeichnet, daß die Intensität des dritten Satzes an ultravioletten Strahlen ungefähr 150 bis 300 mW/cm$^2$ in einem Wellenlängenbereich von ungefähr 360 bis 370 nm und ungefähr 50 bis 150 mW/ cm$^2$ in einem Wellenlängenbereich von ungefähr 250 bis 260 nm beträgt.

25. Verfahren nach Anspruch 19 oder einem davon abhängigen Anspruch, dadurch gekennzeichnet, daß der dritte Satz an ultravioletten Strahlen für weniger als eine Minute auf die Linse gerichtet wird.

26. Verfahren nach Anspruch 20 oder einem davon abhängigen Anspruch, dadurch gekennzeichnet, daß die Linse für weniger als ungefähr 30 Minuten aufgewärmt wird, nachdem der dritte Satz an ultravioletten Strahlen auf die Linse gerichtet worden ist.

27. Vorrichtung zum Herstellen einer Kunststofflinse, umfassend: ein erstes Formglied (78); ein zweites Formglied (78), räumlich getrennt von dem ersten Formglied (78), wobei das erste Formglied und das zweite Formglied jeweils eine Fläche (86) aufweisen und einen Formenhohlraum (82) festlegen; ein Ultraviolettlichtgenerator (40) zum Erzeugen von ultraviolettem Licht und Richten desselben auf das erste und/oder zweite Formglied im Betrieb; einen Ultraviolettlichtfilter (54), angeordnet zwischen dem Ultraviolettlichtgenerator und dem ersten Formglied und zwischen dem Ultraviolettlichtgenerator und dem zweiten Formglied; dadurch gekennzeichnet, daß die Vorrichtung ferner einen Verteiler (94) aufweist, geeignet, Luft mit einer Temperatur von zwischen 0 °C und weniger als 20°C auf das erste und zweite Formglied zu richten, während das ultraviolette Licht im wesentlichen simultan auf das erste und/ oder zweite Formglied im Betrieb gerichtet ist, wobei der Verteiler angeschlossen ist, um Luft im Betrieb von den Kanten des ersten Formglieds in der Mitte des ersten Formglieds und von den Kanten des zweiten Formglieds in die Mitte des zweiten Formglieds zu verteilen.

28. Vorrichtung nach Anspruch 27, dadurch gekennzeichnet, daß die Lufttemperatur ungefähr 0 bis 15 °C beträgt.

29. Vorrichtung nach Anspruch 28, dadurch gekennzeichnet, daß die Lufttemperatur ungefähr 0 bis 10 °C beträgt.

30. Vorrichtung nach Anspruch 29, dadurch gekennzeichnet, daß die Lufttemperatur ungefähr 3 bis 8 °C beträgt.

31. Vorrichtung nach einem der Ansprüche 27 bis 30, dadurch gekennzeichnet, daß der Formenhohlraum zylindrisch ist, und die Höhe des Hohlraums über den Durchmesser variiert.

32. Vorrichtung nach einem der Ansprüche 27 bis 31, dadurch gekennzeichnet, das der Filter (54) angeordnet ist, um ultraviolettes Licht im Betrieb mit einer Intensität zu führen, die proportional zu der Höhe des Hohlraums variiert.

33. Vorrichtung nach einem der Ansprüche 27 bis 32, dadurch gekennzeichnet, daß der Filter (54) eine Scheibe aus opakem Material zum Reduzieren der Intensität an ultraviolettem Licht, das die Mitte der Formglieder erreicht, relativ zu der Intensität an ultraviolettem Licht, das die Kante der Formglieder erreicht, im Betrieb, umfaßt.

34. Vorrichtung nach einem der Ansprüche 27 bis 33, dadurch gekennzeichnet, daß der Filter (54) einen Ring aus opakem Material zum Reduzieren der Intensität an ultraviolettem Licht, das die Kante der Formglider erreicht, relativ zu der Intensität an ultraviolettem Licht, das die Mitte der Formglieder erreicht, im Betrieb, umfaßt.

35. Vorrichtung nach einem der Ansprüche 27 bis 34, dadurch gekennzeichnet, daß der Filter (54) ein transparentes Lagenmaterial umfaßt, das eine Vielzahl von Formen, die darauf gedruckt sind, aufweist, die ultraviolettes Licht absolutierend sind.

36. Vorrichtung nach Anspruch 35, dadurch gekennzeichnet, daß die Dichte pro Einheitsfläche der Formen an einem Punkt ein Minimum aufweist, der den größten Abstand zwischen dem ersten Formglied (78) und dem zweiten Formglied (78) darstellt, und die Dichte pro Einheitsfläche der Formen an einem Punkt ein Maximum aufweist, der dem kleinsten Abstand zwischen dem ersten Formglied und dem zweiten Formglied entspricht.

37. Vorrichtung nach einem der Ansprüche 27 bis 36, dadurch gekennzeichnet, daß der Verteiler (94) eine Luftdüse umfaßt, die eine im wesentlichen zylindrische Bohrung (96) umfaßt, und die Bohrung eine Vielzahl von Öffnungen (98) aufweist, die um ihren Umfang herum angeordnet sind.

38. Vorrichtung nach Anspruch 37, dadurch gekennzeichnet, daß der durchschnittliche Durchmesser der Öffnungen (98) in der Luftdüse um den Umfang der Bohrung (96) herum variiert.

39. Vorrichtung nach einem der Ansprüche 37 oder 38, dadurch gekennzeichnet, daß die Luftdüse einen Lufteinlaß umfaßt, und der Durchmesser der Öffnungen (98) ein Minimum benachbart zu dem Lufteinlaß (12) hat, und der Durchmesser der Öffnungen an einem Punkt entlang des Umfangs der Bohrung, der den Bohrungen, die einen minimalen Durchmesser aufweisen, gegenüber liegt, maximal ist.

40. Vorrichtung nach einem der Ansprüche 27 bis 39, dadurch gekennzeichnet, daß der Verteiler (94) dazu geeignet ist, im Betrieb ungefähr 0,028 bis 0,850 Standardkubikmeter (1 bis 30 Standardkubikfuß) pro Minute auf das erste Formglied (78) zu richten, um das erste Formglied zu kühlen, und ungefähr 0,038 bis 0,850 Standardkubikmeter (30 Standardkubikfuß) pro Minute auf das zweite Formglied (78) zu richten, um das zweite Formglied zu kühlen.

41. Vorrichtung nach Anspruch 40, dadurch gekennzeichnet, daß der Verteiler (94) dazu geeignet ist, im Betrieb ungefähr 0,113 bis 0,566 Standardkubikmeter (4 bis 20 Standardkubikfuß) pro Minute auf das erste Formglied (78) zu richten, um das erste Formglied zu kühlen, und ungefähr 0,113 bis 0,566 Standardkubikmeter (4 bis 20 Standardkubikfuß) pro Minute auf das zweite Formglied (78) zu richten, um das zweite Formglied zu kühlen.

42. Vorrichtung nach Anspruch 40, dadurch gekennzeichnet, daß der Verteiler (94) dazu geeignet ist, im Betrieb ungefähr 0,255 bis 0,423 Standardkubikmeter (9 bis 15 Standardkubikfuß) pro Minute auf das erste Formglied zu richten, um das erste Formglied (78) zu kühlen, und 0,255 bis 0,423 Standardkubikmeter (9 bis 15 Standardkubikfuß) pro Minute auf das zweite Formglied (78) zu führen, um das zweite Formglied zu kühlen.

43. Vorrichtung nach einem der Ansprüche 27 bis 42, dadurch gekennzeichnet, daß das erste und das zweite Formglied (78) jeweils eine Dicke von weniger als ungefähr 0,5 mm aufweisen.

44. Vorrichtung nach Anspruch 43, dadurch gekennzeichnet, daß die Formglieder (78) eine Dicke von ungefähr 2,0 bis 4,0 mm aufweisen.

45. Vorrichtung nach Anspruch 43, dadurch gekennzeichnet, daß die Formglieder (78) eine Dicke von ungefähr 2,5 bis 3,5 mm aufweisen.

46. Vorrichtung nach einem der Ansprüche 27 bis 45, ferner gekennzeichnet durch einen zweiten Ultraviolettlichtgenerator (304) zum Erzeugen von ultraviolettem Licht und Richten desselben auf die Linse im Betrieb und einen Erhitzer (306), um die Linse im Betrieb aufzuwärmen.

47. Vorrichtung nach Anspruch 46, ferner gekennzeichnet durch einen dritten Ultraviolettlichtgenerator (308) zum Erzeugen von ultraviolettem Licht und Richten desselben auf die Linse im Betrieb, nachdem die Linse aufgewärmt worden ist.

48. Vorrichtung nach Anspruch 47, ferner gekennzeichnet durch einen zweiten Erhitzer (310), um die Linse im Betrieb zu erwärmen, nachdem der dritte Ultraviolettlichtgenerator (308) Licht auf die Linse gerichtet hat.

**Revendications**

1. Un procédé pour fabriquer une lentille en plastique, comprenant : placer une matière de formage de lentille pouvant être polymérisée dans une cavité de moule (82) définie entre un premier élément de moule (78) avec une face (86), et un second élément de moule (78) avec une face (86) et un joint (80) ; et diriger des rayons ultraviolets (40) vers au moins l'un des premier ou second éléments de moule ou ledit joint tout en refroidissant sensiblement simultanément le premier élément de moule et le second élément de moule, caractérisé en ce que le refroidissement est effectué en dirigeant de l'air à une température entre 0°C et moins de 20°C vers les faces des premier et second éléments de moule, l'air étant dirigé depuis les bords du premier élément de moule vers le centre du premier élément de moule, et depuis les bords du second élément de moule vers le centre du second élément de moule.

2. Le procédé de la revendication 1 selon lequel la température de l'air est d'environ 0-15°C.

3. Le procédé de l'une quelconque des revendications ci-dessus selon lequel la température de l'air est d'environ 0-10°C.

4. Le procédé de l'une quelconque des revendications ci-dessus selon lequel la température de l'air est d'environ 3-8°C.

5. Le procédé de l'une quelconque des revendications ci-dessus selon lequel la cavité de moule (82) est sensiblement cylindrique et la hauteur de la cavité varie en travers du diamètre de la cavité ; et selon lequel l'intensité des rayons ultraviolets varie approximativement en proportion de la hauteur de la cavité.

6. Le procédé de l'une quelconque des revendications ci-dessus, comprenant en outre diriger de l'air à un débit d'environ 0,028-0,850 mètres cubes standard (1-30 pieds cubes standard) par minute vers le premier élément de moule pour refroidir le premier élément de moule, et diriger de l'air à un débit d'environ 0,028-0,850 mètres cubes standard (1-30 pieds cubes standard) par minute vers le second élément de moule pour refroidir le second élément de moule.

7. Le procédé de la revendication 6 selon lequel le débit de l'air en contact avec le premier élément de moule est d'environ 0,113-0,566 mètres cubes standard (4-20 pieds cubes standard) par minute, et le débit de l'air en contact avec le second élément de moule est d'environ 0,113-0,566 mètres cubes standard (4-20 pieds cubes standard) par minute.

8. Le procédé de la revendication 6 selon lequel le débit de l'air en contact avec le premier élément de moule est d'environ 0,255-0,423 mètres cubes standard (9-15 pieds cubes standard) par minute, et le débit de l'air en contact avec le second élément de moule est d'environ 0,255-0,423 mètres cubes standard (9-15 pieds cubes standard) par minute.

9. Le procédé de l'une quelconque des revendications ci-dessus selon lequel la cavité de moule est définie en partie entre un premier élément de moule (78) d'épaisseur environ 1,0-50 mm et un second élément de moule (78) d'épaisseur environ 1,0-5,0 mm.

10. Le procédé de la revendication 9 selon lequel le premier ou second élément de moule (78) a une épaisseur d'environ 2,0-4,0 mm.

11. Le procédé de la revendication 9 selon lequel le premier ou second élément de moule (78) a une épaisseur d'environ 2,5-3,5 mm.

12. Le procédé de l'une quelconque des revendications ci-dessus selon lequel la matière de formage de lentille pouvant être polymérisée est placée dans une cavité de moule définie en partie entre le premier élément de moule et un second élément de moule séparés par un joint annulaire, et selon lequel les rayons de lumière ultraviolette sont dirigés à travers le joint annulaire pour recuire la matière de formage de lentille.

13. Le procédé de la revendication 12, comprenant en outre empêcher les rayons de lumière ultraviolette d'entrer en contact avec les premier ou second éléments de moule.

14. Un procédé conforme à l'une quelconque des revendications 1-11 pour fabriquer une lentille en plastique avec une courbure souhaitée, selon lequel la cavité définit une courbure théorique qui est différente de la courbure souhaitée ; et selon lequel lesdits rayons ultraviolets sont dirigés vers au moins l'un des premier et second éléments de moule de sorte que des portions de la matière dans la cavité reçoivent des intensités différentes de lumière ultraviolette depuis d'autres portions de la matière dans la cavité, afin de permettre à la matière de former une lentille avec la courbure souhaitée.

15. Le procédé de la revendication 14, comprenant en outre démouler la lentille, et chauffer la lentille.

16. Le procédé de la revendication 15 selon lequel le chauffage forme la lentille avec la courbure souhaitée.

17. Le procédé de l'une quelconque des revendications 14-16 selon lequel l'intensité des rayons ultraviolets varie en travers des premier ou second éléments de moule de sorte que la matière se corrige pour former la lentille avec la courbure souhaitée.

18. Le procédé de l'une quelconque revendication 1-11 ou 14-17, selon lequel les rayons ultraviolets sont dirigés avec une intensité totale de moins d'environ 10 mW/cm$^2$ vers au moins l'un des éléments de moule pour recuire la matière pour former une lentille, et comprenant en outre démouler la lentille à la suite de ladite étape de refroidissement et ensuite diriger un second ensemble de rayons ultraviolets vers la lentille à une intensité d'environ 150-300 mW/cm$^2$ dans une gamme de longueur d'onde d'environ 360-370 nm, et d'environ 50-150 mW/cm$^2$ dans une gamme de longueur d'onde d'environ 250-260 nm.

19. Le procédé de la revendication 18, comprenant en outre diriger un troisième ensemble de rayons ultraviolets vers la lentille.

20. Le procédé de la revendication 19, comprenant en outre chauffer la lentille après que le troisième ensemble de rayons ultraviolets est dirigé vers la lentille.

21. Le procédé de la revendication 20 selon lequel la lentille est chauffée à une température d'environ 65-180°C.

22. Le procédé de la revendication 20-21 selon lequel la lentille est chauffée pendant moins d'environ 30 minutes.

23. Le procédé de l'une quelconque des revendications 19-22 selon lequel le second ensemble de rayons ultraviolets est dirigé vers une lentille pendant moins d'environ 1 minute.

24. Le procédé de la revendication 19 ou de l'une quelconque revendication dépendant de celle-ci, selon lequel l'intensité du troisième ensemble de rayons ultraviolets est d'environ 150-300 $mW/cm^2$ dans une gamme de longueur d'onde d'environ 360-370 nm, et d'environ 50-150 $mW/cm^2$ dans une gamme de longueur d'onde d'environ 250-260 nm.

25. Le procédé de la revendication 19 ou de l'une quelconque revendication dépendant de celle-ci, selon lequel le troisième ensemble de rayons ultraviolets est dirigé vers la lentille pendant moins de 1 minute.

26. Le procédé de la revendication 20 ou de l'une quelconque revendication dépendant de celle-ci, selon lequel la lentille est chauffée pendant moins d'environ 30 minutes après que le troisième ensemble de rayons ultraviolets est dirigé vers la lentille.

27. Appareil pour fabriquer une lentille en plastique, comprenant : un premier élément de moule (78) ; un second élément de moule (78) distant du premier élément de moule (78), les premier et second éléments de moule ayant chacun une face (86) et définissant une cavité de moule (82) ; un générateur de lumière ultraviolette (40) pour générer et diriger de la lumière ultraviolette vers au moins l'un des premier et second éléments de moule durant l'utilisation ; un filtre de lumière ultraviolette (54) disposé entre le générateur de lumière ultraviolette et le premier élément de moule et entre le générateur de lumière ultraviolette et le second élément de moule ; caractérisé en ce que l'appareil comprend en outre un distributeur (94) adapté pour diriger de l'air à une température entre 0°C et moins de 20°C vers les premier et second éléments de moule tandis que la lumière ultraviolette est dirigée sensiblement simultanément vers au moins l'un des premier et second éléments de moule durant l'utilisation, le distributeur étant connecté pour distribuer de l'air durant l'utilisation depuis les bords du premier élément de moule vers le centre du premier élément de moule, et depuis les bords du second élément de moule vers le centre du second élément de moule.

28. L'appareil de la revendication 27 dans lequel la température de l'air est d'environ 0-15°C.

29. L'appareil de la revendication 28 dans lequel la température de l'air est d'environ 0-10°C.

30. L'appareil de la revendication 29 dans lequel la température de l'air est d'environ 3-8°C.

31. L'appareil de l'une quelconque des revendications 27-30 dans lequel la cavité de moule est cylindrique et la hauteur de la cavité varie en travers du diamètre de la cavité.

32. L'appareil de l'une quelconque des revendications 27-31 dans lequel le filtre (54) est positionné pour diriger la lumière ultraviolette durant l'utilisation avec une intensité qui varie en proportion de la hauteur de la cavité.

33. L'appareil de l'une quelconque des revendications 27-32 dans lequel le filtre (54) comprend un disque de matière opaque pour réduire l'intensité de lumière ultraviolette atteignant le centre des éléments de moule par rapport à l'intensité de lumière ultraviolette atteignant le bord des éléments de moule durant l'utilisation.

34. L'appareil de l'une quelconque des revendications 27-33 dans lequel le filtre (54) comprend une bague de matière opaque pour réduire l'intensité de lumière ultraviolette atteignant le bord des éléments de moule par rapport à l'intensité de lumière ultraviolette atteignant le centre des éléments de moule durant l'utilisation.

35. L'appareil de l'une quelconque des revendications 27-34 dans lequel le filtre (54) comprend un matériau en feuille

transparente ayant une pluralité de motifs d'absorption de lumière ultraviolette imprimés sur celle-ci.

36. L'appareil de la revendication 35 dans lequel la densité par unité de surface des motifs est à un minimum en un point correspondant à la plus grande distance entre le premier élément de moule (78) et le second élément de moule (78) et dans lequel la densité par unité de surface des motifs est à un maximum en un point correspondant à la plus petite distance entre le premier élément de moule et le second élément de moule.

37. L'appareil de l'une quelconque des revendications 27-36 dans lequel le distributeur (94) comprend un ajutage ayant un alésage sensiblement cylindrique (96), et l'alésage a une pluralité d'orifices (98) disposés autour de la périphérie de celui-ci.

38. L'appareil de la revendication 37 dans lequel le diamètre moyen des orifices (98) dans l'ajutage varie autour de la périphérie de l'alésage (96).

39. L'appareil de l'une quelconque des revendications 37 ou 38 dans lequel l'ajutage comprend une entrée d'air et le diamètre des orifices (98) est à un minimum du côté de l'entrée d'air (12), et le diamètre des orifices est à un maximum en un point le long de la périphérie de l'alésage qui est opposé aux orifices ayant un diamètre minimum.

40. L'appareil de l'une quelconque des revendications 27-39 dans lequel le distributeur (94) est adapté pour diriger durant l'utilisation environ 0,028-0,850 mètres cubes standard (1-30 pieds cubes standard) par minute vers le premier élément de moule (78) pour refroidir le premier élément de moule, et environ 0,038-0,850 mètres cubes standard (30 pieds cubes standard) par minute vers le second élément de moule (78) pour refroidir le second élément de moule.

41. L'appareil de la revendication 40 dans lequel le distributeur (94) peut être adapté pour diriger durant l'utilisation environ 0,113-0,566 mètres cubes standard (4-20 pieds cubes standard) par minute vers le premier élément de moule (78) pour refroidir le premier élément de moule, et environ 0,113-0,566 mètres cubes standard (4-20 pieds cubes standard) par minute vers le second élément de moule (78) pour refroidir le second élément de moule.

42. L'appareil de la revendication 40 dans lequel le distributeur (94) peut être adapté pour diriger durant l'utilisation environ 0,255-0,423 mètres cubes standard (9-15 pieds cubes standard) par minute vers le premier élément de moule pour refroidir le premier élément de moule (78), et environ 0,255-0,423 mètres cubes standard (9-15 pieds cubes standard) par minute vers le second élément de moule (78) pour refroidir le second élément de moule.

43. L'appareil de l'une quelconque des revendications 27-42 dans lequel les premier et second éléments de moule (78) ont chacun une épaisseur de moins d'environ 5,0 mm.

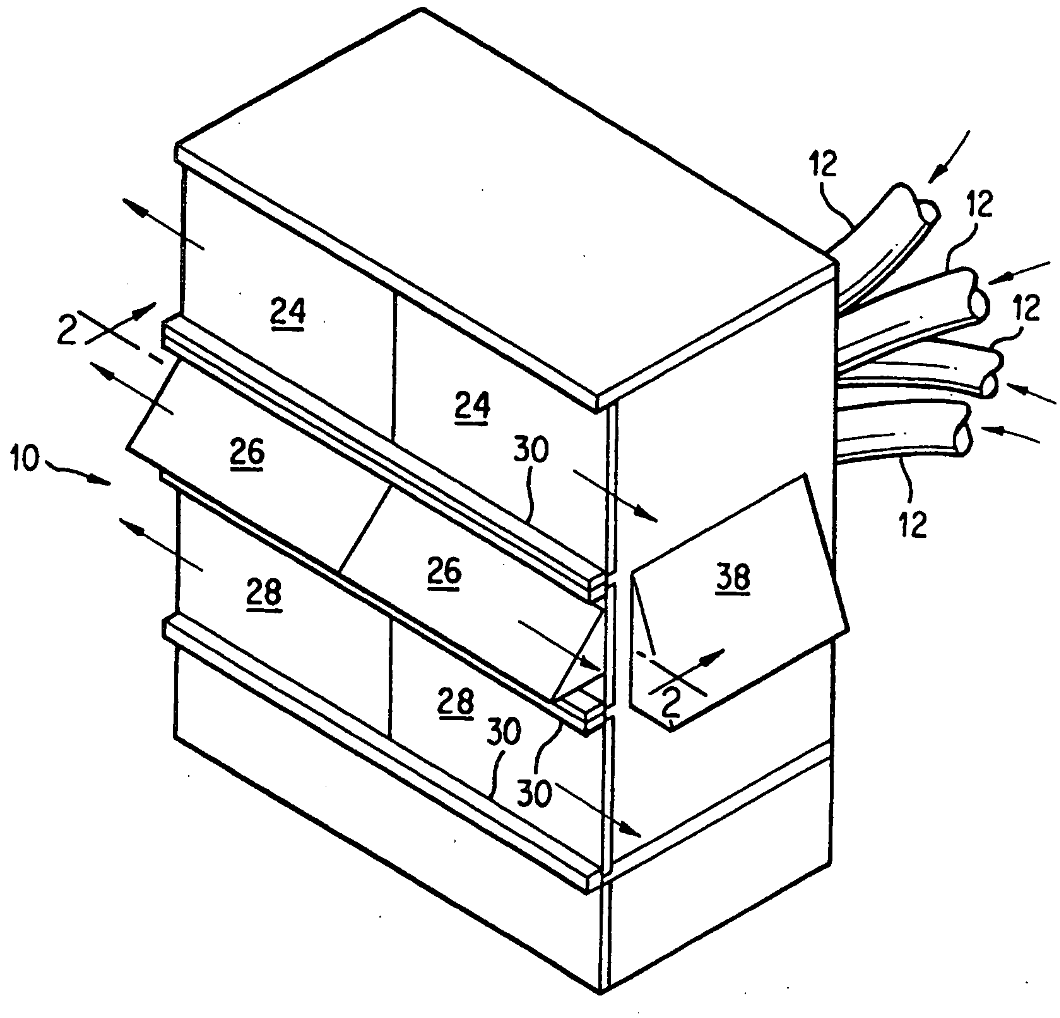
44. L'appareil de la revendication 43 dans lequel les éléments de moule (78) ont une épaisseur d'environ 2,0-4,0 mm.

45. L'appareil de la revendication 43 dans lequel les éléments de moule (78) ont une épaisseur d'environ 2,5-3,5 mm.

46. L'appareil de l'une quelconque des revendications 27-45, comprenant en outre un second générateur de lumière ultraviolette (304) pour générer et diriger de la lumière ultraviolette vers la lentille durant l'utilisation, et un premier élément de chauffage (306) pour chauffer la lentille durant l'utilisation.

47. L'appareil de la revendication 46, comprenant en outre un troisième générateur de lumière ultraviolette (308) pour générer et diriger de la lumière ultraviolette contre la lentille durant l'utilisation après que la lentille a été chauffée.

48. L'appareil de la revendication 47, comprenant en outre un second élément de chauffage (310) pour chauffer la lentille durant l'utilisation après que le troisième générateur de lumière ultraviolette (308) a dirigé la lumière contre la lentille.




F I G. 1

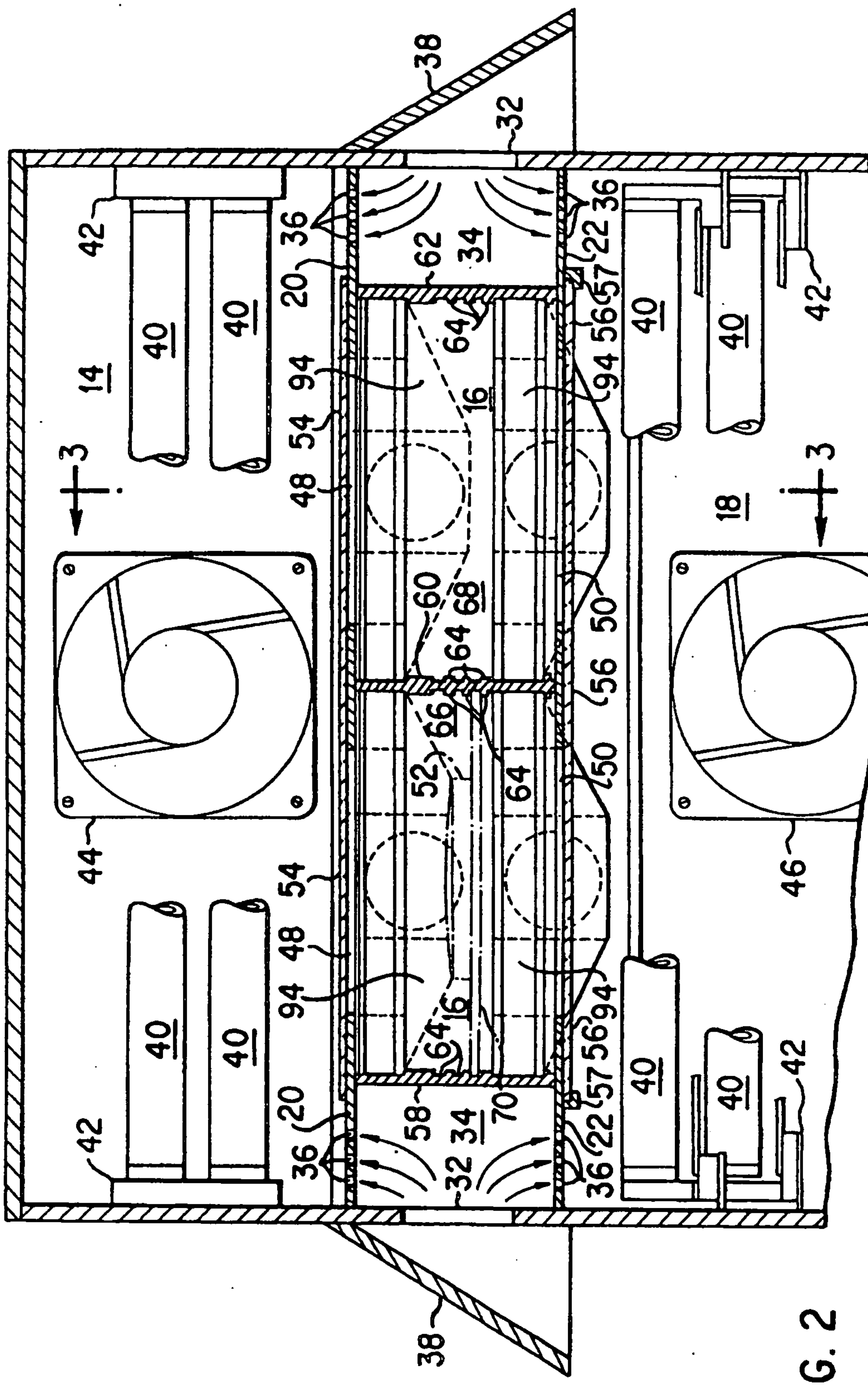

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FIG. 2

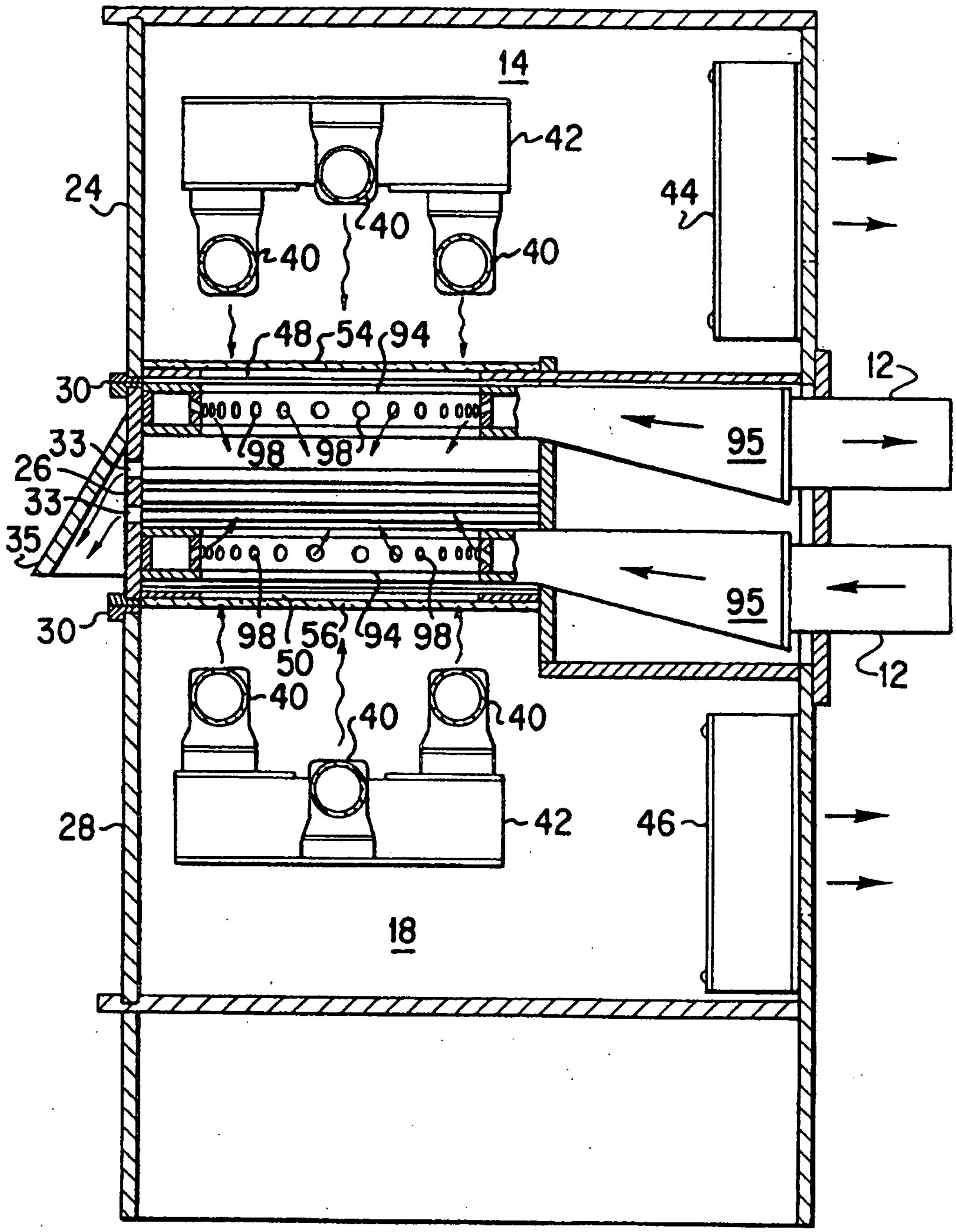
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FIG. 3

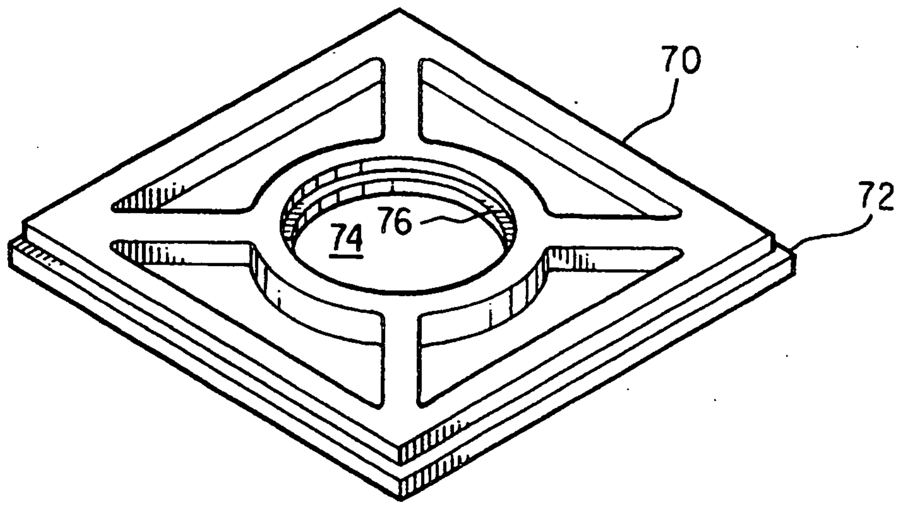


FIG. 4

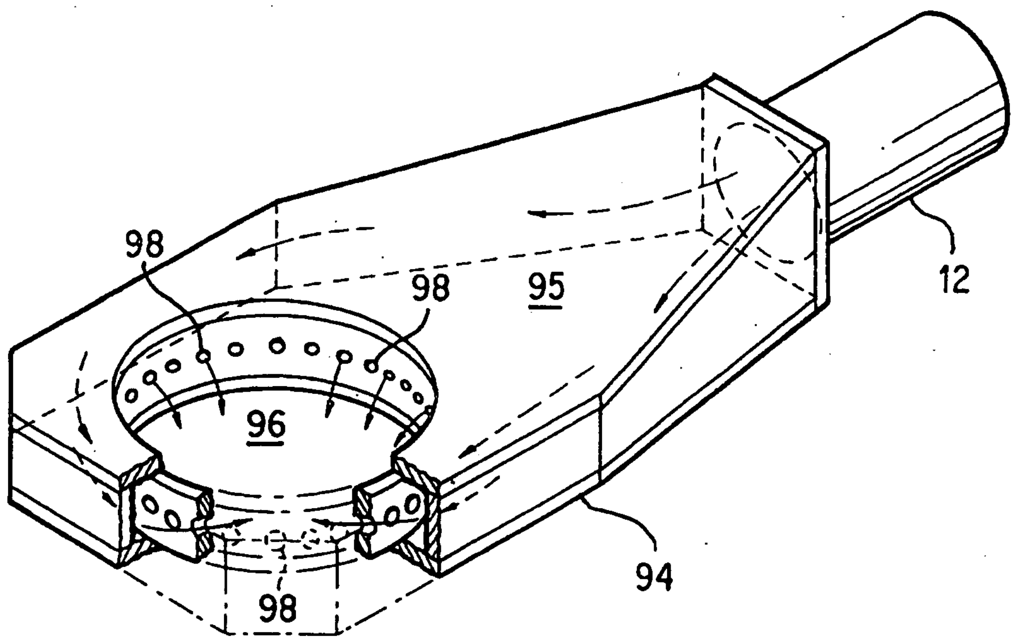


FIG. 5

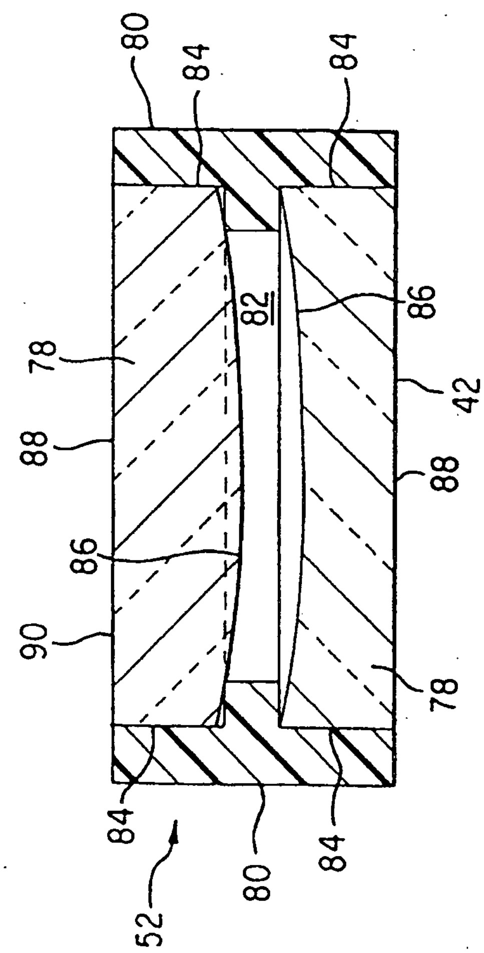
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FIG. 6

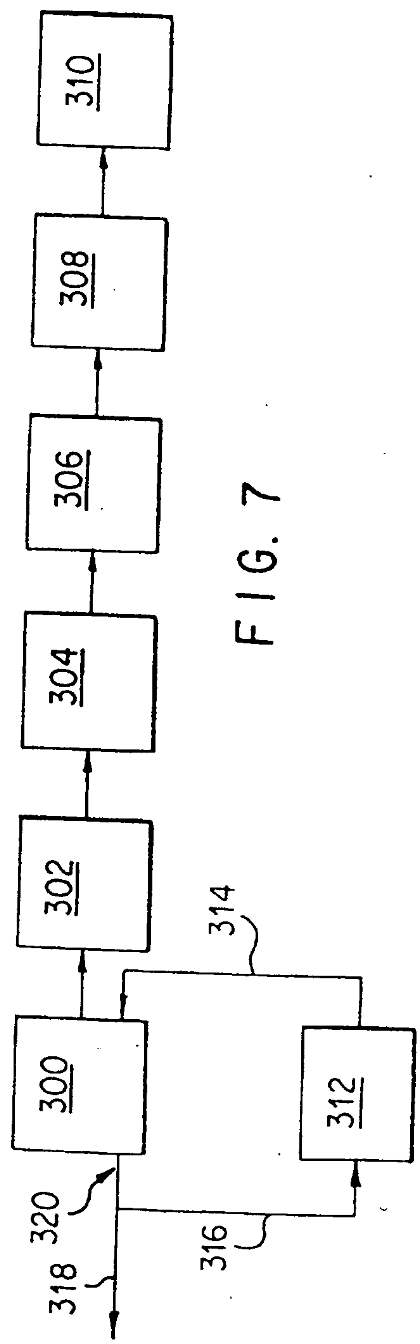
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FIG. 7